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EXPERIMENTAL CALIBRATION OF THE NSWC EXPANDED LARGE SCALE GAP TEST

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FOREWORD

The NSWC Expanded Large Scale Gap Test (ELSGT) is to be used as the standard test, for the UN and the NATO, to determine the shock sensitivity of candidate extremely insensitive detonating substances (EIDS). These EIDS are to be used in extremely insensitive articles which do not constitute a mass detonation hazard (class/division 1.6).

This report presents the first complete experimental calibration of the ELSGT and the techniques used to obtain the calibration data. The study was performed for the Department of Defense Explosives Safety Board (DDESB), Code KT, under the cognizance of Dr. J. N. Ward.

Grateful thanks to R. Hay (R13) for absolutely superb trace reading work. As a result the (x, t) data presented here are of the highest quality. The authors also are grateful to H. Sandusky and C. Groves for their independent verification of the data. Thanks also to R. Bernecker for his support and interest. This work would not have been possible without the encouragement and inspiration of M. Swisdak.

Approved by:

William H. Bohli

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ABSTRACT

The NSWC ELSGT is to be used as the standard test for the UN and the NATO to determine the shock sensitivity of candidate extremely insensitive detonating substances. This report presents the first complete experimental calibration of the ELSGT and the techniques used to obtain the calibration data. In particular a improved method of differentiating photographic streak camera (x, t) data is described.

Streak camera data must be numerically differentiated to obtain wave velocities as functions of time or distance. For time-varying or structured data, techniques such as spline or polynomial fitting are frequently employed. These techniques are usually adjusted by the researcher until the results are acceptable. Consequently, the results can be biased by the method. A new, unbiased, efficient, and accurate method based on the Kaiser and Reed algorithm is described. This method will be demonstrated by its application to the first experimental calibration of the ELSGT.

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CHAPTER 1

INTRODUCTION

The NSWC Expanded Large Scale Gap Test[1] (ELSGT) is to be used as the standard test, for the UN and the NATO, to determine the shock sensitivity of candidate extremely insensitive detonating substances (EIDS). These EIDS are to be used in extremely insensitive articles which do not constitute a mass detonation hazard (class/division 1.6). This report presents the first complete experimental calibration of the ELSGT and the techniques used to obtain the calibration data.

The ELSGT was designed to measure the shock sensitivity to detonation of explosives; it is a larger scale version of the NSWC Large Scale Gap Test (LSGT).[2] A pentolite explosive donor charge propagates a shock into a polymethyl methacrylate (PMMA) attenuator, the gap; see Figure 1-1. The gap then transmits the shock into the explosive acceptor being tested. The ELSGT donor and gap diameters are both 95.25 mm. By varying the length of the gap the pressure transmitted to the interface between the explosive acceptor and the gap can be controlled.

By definition the failure diameter is that diameter below which the explosive cannot sustain detonation, so the explosive cannot be tested to determine the shock necessary for detonation below that diameter. Both the LSGT and ELSGT methods provide steel confinement for the material under test, the acceptor. The confinement increases the apparent diameter of the acceptor by delaying the arrival of rarefactions from the outer surfaces. However the LSGT cannot be used for materials of <u>confined</u> failure diameters greater than 50 mm. The larger diameter ELSGT, therefore, can be used to test insensitive materials that tend to have <u>confined</u> failure diameters less than 95 mm; this range is suitable for most materials.

The calibration described here is based on a careful measurement of the velocity of the shock U_S propagated along the central axis of the cylindrical PMMA gap. The pressure corresponding to U_S was then calculated using the following well known relationship,

$$p - p_0 = \rho_o u_p U_s \qquad (1\text{-}1)$$

This relationship is based on the conservation of mass and momentum. Here ρ_0 is the density of the PMMA, u_p the particle or mass velocity and the original pressure, p_0 is small ($\approx 10^5$ Pa) so it is neglected in this study.

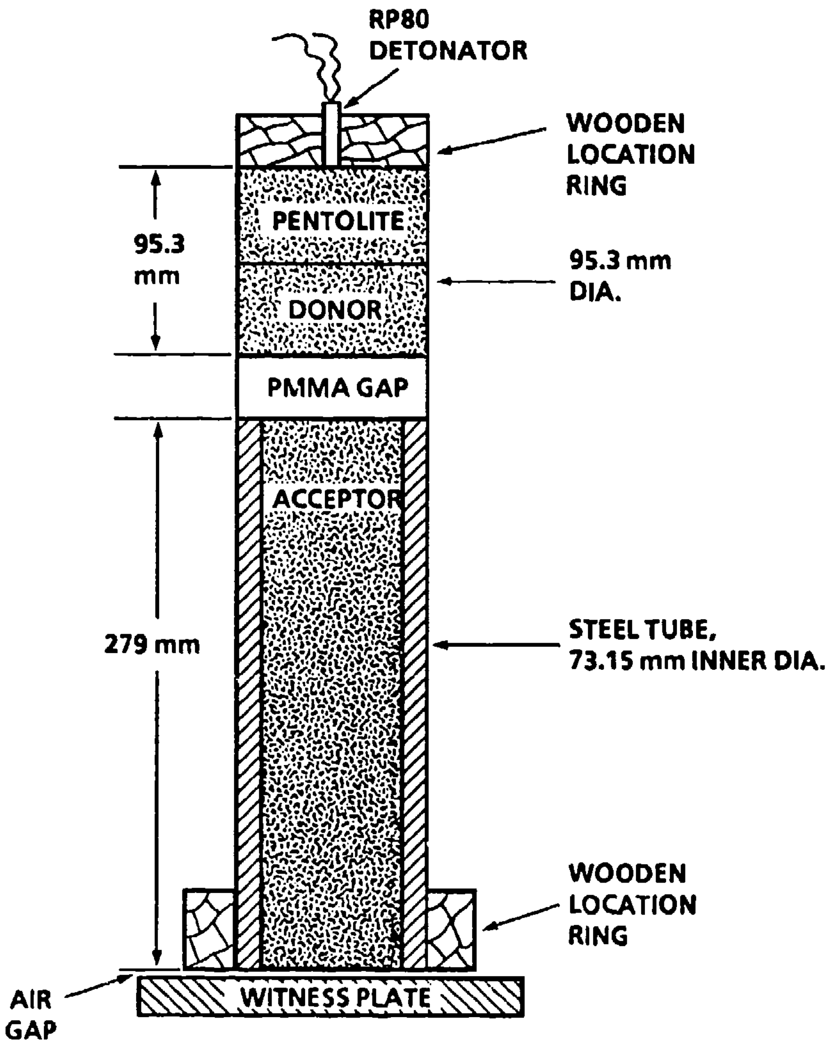

FIGURE 1-1. ELSGT GAP TEST ASSEMBLY

The particle velocity can be obtained by direct measurement or from well documented experimental shock Hugoniot data that relate u_p to U_S. A typical Hugoniot is in the form of a straight line, e.g., $U_S = a\ u_p + b$ where a and b are constants, or sometimes a polynomial. In this study, the particle velocities in PMMA have been obtained from published Hugoniot data and not by direct measurement.

The shock velocity U_S data presented here are believed to be of the highest precision and accuracy. The particle velocity data and thus the pressure calibration data can be influenced by the choice of the shock Hugoniot used. An example of the likely inaccuracies of these pressure data due to the choice of Hugoniot is presented. The results could be verified by direct particle velocity or pressure measurements. This would be done using ***in situ*** gauges at discrete positions in the PMMA attenuator.

The estimated mean error of the pressure calibration is between 1.6 and 4.1 percent between 9 and 100 mm of PMMA attenuator distance. These errors are largely due to the method of estimating particle velocity, i.e., from the measured shock velocity and published Hugoniot data. The uncertainty of the calculation of shock velocities from the streak photograph data, using the NERD filter method described in Chapter 3, was estimated to be only 0.05 percent.

CHAPTER 2

EXPERIMENTAL METHOD

THE ELSGT TEST CALIBRATION ASSEMBLY

Components

Donors. The calibration assembly is shown in Figure 2-1. The two donor charges were pressed to a density of nominally 1560 ± 10 kg/m^3 by Chemtronics, Inc., Swannanoa, North Carolina. They were both 95.25 mm diameter and 47.5 mm high. The faces of the donor assembly and the PMMA gap were joined with thin layers of cyano acrylate adhesive (Eastman 910) to exclude air.

PMMA gaps. The PMMA gaps were accurately machined from cast, annealed, UV grade PMMA of 1186 kg/m^3 density. The gaps were lapped and polished to lengths of 70.0 mm for experiments #E673 and #E675, and 150 mm for #E674. The diameters were polished to 95.25 mm (3.75"), as supplied by the manufacturer. The original rounded cylindrical surfaces on the sides of the cylinders were slightly rippled. However, the progress of the detonation front must be observed through these curved sides, and errors would result if these surfaces were distorted. The distortion was avoided by machining parallel flats, 12.7 mm wide, along the length of the PMMA cylinders; these were lapped and polished flat to optical clarity. The use of parallel flats is similar to the techniques reported by Erkman.[3]

Detonator. A Reynolds RP80 exploding bridge wire detonator was used to initiate the donor charges. This was held in the center of the first donor by a wooden locating disk.

Optical Techniques

The experiments were performed at NSWC White Oak, in September 1988, using a 'Cordin 132' streak camera to measure the shock velocity of the attenuated wave in the PMMA attenuating cylinder, the 'gap'.

The streak images were focussed onto the camera slit with a 1000 mm lens. Care was taken to ensure that the lens was focussed exactly onto the central axis of the PMMA cylinder, and that the axis was exactly aligned parallel to the camera slit. The alignment is described below.

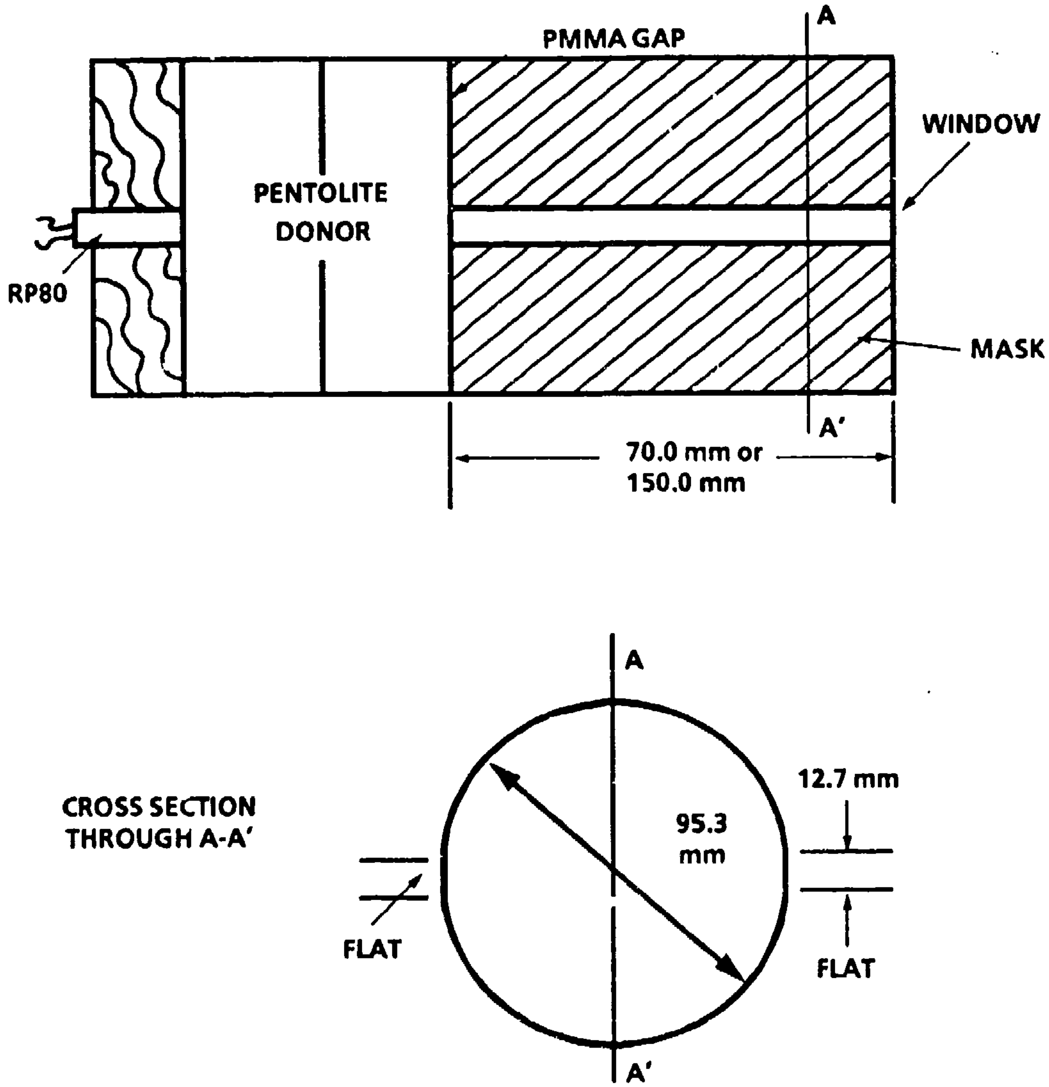

FIGURE 2-1. CALIBRATION ASSEMBLY

Focussing and Alignment

The use of a special focussing device eliminated errors caused by poor lens focussing or lack of parallelism between the gap axis and the streak camera slit. It also eliminated displacement errors due to refraction in the PMMA block; these would otherwise increase the image magnification, and thus the observed velocity, by ≈0.65 percent; see Appendix A.

Focussing device. The focussing device was manufactured from a 95.25 mm diameter PMMA cylinder that had been carefully machined into two halves. The cut surface of one half was lapped and polished flat onto the exact center axis of the cylinder, hence it had a 'D' cross-section. This polished surface was parallel to the 12.7 mm flat on the front, curved surface of the cylinder. A calibrated scale was attached to the axial flat to facilitate focussing. A front-silvered mirror was glued to the 12.7 mm flat. The whole device was mounted on the shot-stand in a V-groove assembly; see Figure 2-2.

The camera slit was back-lit and its image projected onto the focussing device's mirror via the camera lens. Alignment was achieved by turning the focussing device until the slit image, reflected by the mirror, exactly coincided with the slit. The lens was then focussed onto the image of the scale at the back of the PMMA half cylinder. Finally the V-groove assembly was clamped into position. The end of the focussing device determined the position of the PMMA/pentolite interface, i.e., the $x = 0$ position.

The focussing device was then removed from the V-groove and replaced by the assembled pentolite and PMMA gap. The V-groove ensured that the axis of the cylindrical gap had been aligned exactly parallel and in focus with the camera slit.

A static photograph was then taken, with the camera slit removed, to measure the optical magnification in the experiment. The slit was replaced for the experiment. The scale image was recorded onto the same photographic film used to record the streak. Consequently, errors due to lack of focus and refraction effects were virtually eliminated. The linearity of the 1000 mm lens was tested by measuring the scale divisions at various positions within the field of view of the experiment. The errors were too small to detect within the accuracy of the trace reading equipment, i.e., 2 μm.

Lighting. All the curved outer surfaces of the PMMA, excluding the two parallel 12.7 mm flats, were covered in black masking tape to exclude stray light. The shot was illuminated from behind with a 75 mm exploding wire light source.[4] The light wire was aligned parallel to the PMMA axis and was masked to a length of ≈1 cm so that it approximated to a point source. The light was collimated with a disposable plastic Fresnel lens.

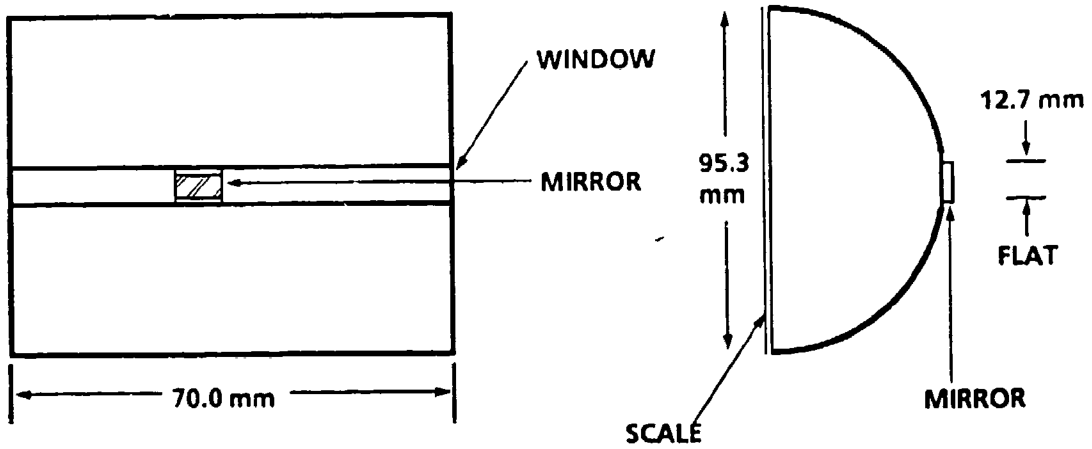

FIGURE 2-2. FOCUSSING DEVICE

Camera speed. The mirror turbine of the streak camera was rotated at a speed chosen to produce streak records that were approximately 45° to the horizontal. The finite width of the camera slit introduces uncertainties in the position of the edge of the streak, and thus errors in trace reading. At 45° these reading errors are minimized.

Optical Results. The resultant streak negatives were of outstanding quality. The edges of the streaks are in excellent focus and of good contrast. The photographic record of experiment #E674 is shown in Figure 2-3.

FIGURE 2-3. STREAK PHOTOGRAPH FOR EXPERIMENT #E674

CHAPTER 3

RESULTS AND DATA ANALYSES

TRACE READING

The streak traces were read with a travelling microscope which was equipped with optical shaft encoders; the resolution and accuracy was ±2 μm. The film negatives were aligned under the microscope so that the time axis was exactly parallel to the horizontal (x) direction of the microscope carriage. The edge of the streak was then read at 50 μm intervals in the x direction. The equally-spaced measurements facilitated subsequent analyses of the data by Fourier transform and Nearly Equal Ripple Differentiation (NERD), see below. The data were transferred to a personal computer for analysis.

The trace reading precision was estimated by making 30 independent measurements at each of 10 individual locations along the streak. In this way the maximum standard deviation of each measurement, from the true streak, was estimated to be 5 μm over the calibrated length of the streak negative.

The streak data were checked and rechecked to minimize errors due to trace reader tilt. The tilt was reduced to less than 10 μm over a 60 mm length of the streak, i.e., < 1/6 mrad.

The optical magnification for each experiment was obtained by careful comparisons of the length of the original focussing scale and its images as viewed through the camera system and the PMMA cylinder.

RAW (x, t) DATA

Two lengths of PMMA attenuator were used: a 70 mm long PMMA attenuator for experiments #E673 and #E675 and a 150 mm attenuator for #E674. The (x, t) data of all three shots are plotted in Figure 3-1. The data are in such good agreement that they appear as one single curve. These data were carefully verified by repeated trace reading to ensure accuracy. The raw (x, t) data for the three experiments are reproduced in Appendix B.

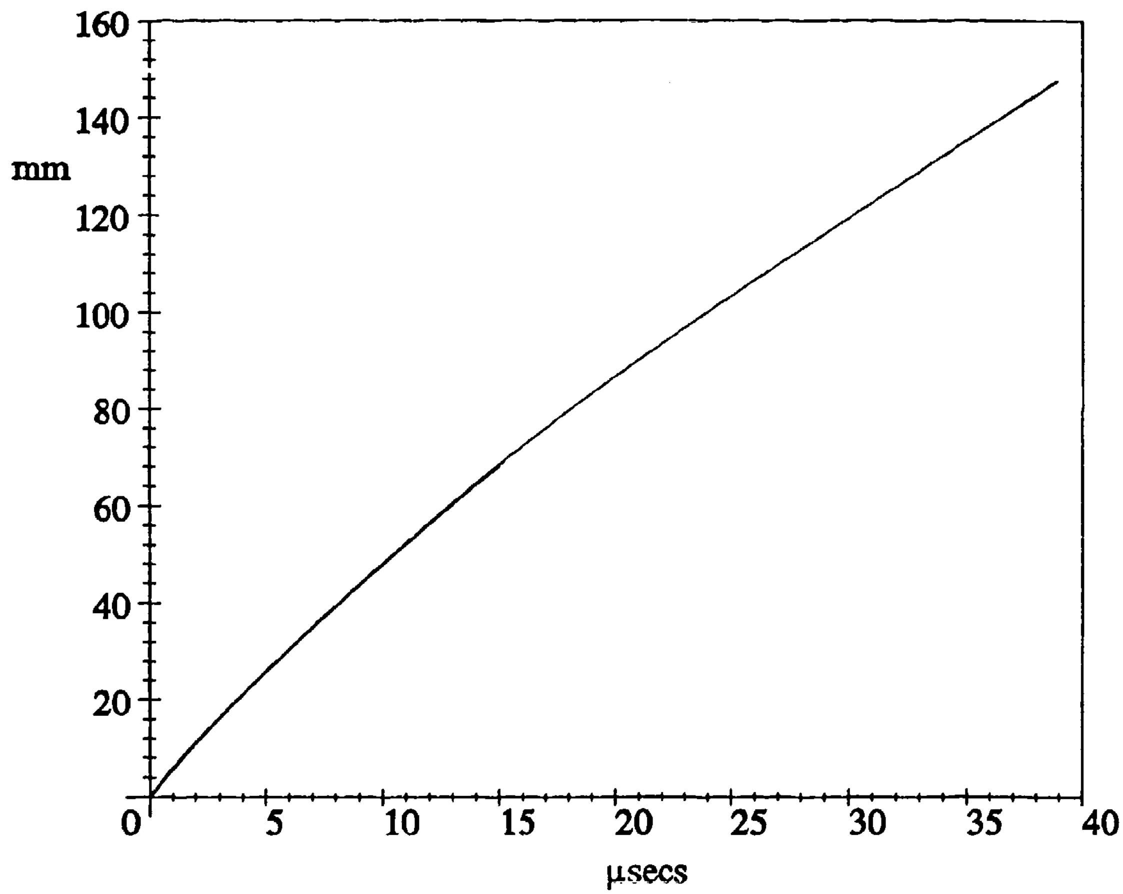

FIGURE 3-1. RAW (x, t) DATA FROM THE THREE EXPERIMENTS

SHOCK VELOCITY OBTAINED USING THE NEARLY EQUAL RIPPLE DIFFERENTIATING (NERD) FILTER

This filter method was developed by Kaiser and Reed;[5] it is discussed in detail in Appendix C. It will be shown that, unlike the more common least squares polynomial and spline fitting methods, the NERD method does not employ any fitting to obtain the results. Consequently, the results are not biassed by the numerical method and the degree of smoothing can be controlled and defined. By comparison, the least squares polynomial and spline fitting techniques rely on subjective assessments of the necessary degree of smoothing; smoothing is usually repeated until the results look acceptable. With these methods the smoothing is never defined in absolute terms.

The NERD method obtains the differentiated and filtered data by convolving the original (x, t) data with a filter function comprised of a set of $2N_p$ coefficients b_k.

$$U_s(t) = \left(\frac{dx}{dt}\right)_t = \sum_{k=1-N_p}^{N_p} b_k \cdot x_{i-k} \tag{3-1}$$

Here x_{i-k} corresponds to the point (x, $\{i-k\}\delta t$) where δt is the time increment. The derivative $(dx/dt)_t$ corresponds to the velocity midway between t and $(t-\delta t)$, i.e., there is a a half-sample delay or numerical shift, this is discussed later in the chapter. The coefficients b_k correspond to the required filter function; they are each defined by β, ϵ, and δ; and they are independent of the (x, t) data. See Appendix C for further details.

The NERD method, as applied here, relies on two properties of the spectrum of differentiated streak data: the narrow, low frequency data bandwidths and the method of differentiation in the frequency domain. To demonstrate these properties we approximate the streak to a straight line: $x = f(t) = Vt$, and $t = -\tau/2$ to $+\tau/2$, where V is a constant (the velocity), t is time, and x is distance.

Bandwidth of the Straight Line

The numerical noise introduced by trace reading has a broad frequency spectrum.[6,7] The spectrum of the streak, on the other hand, has an extremely narrow, low frequency spectrum. Consequently, it is possible to use filtering techniques to selectively attenuate the noise with little effect on the required streak data.

It can be shown that the Fourier spectrum $\mathfrak{F}(\omega)$ can be defined as

$$\mathfrak{F}(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} f(t)\, e^{-j\omega t} dt = \frac{V}{\sqrt{2\pi}} \int_{-\tau/2}^{+\tau/2} t\, e^{-j\omega t} dt \tag{3-2}$$

$$\text{then} \quad \Im(\omega) = \frac{-2jV}{\sqrt{2\pi}} \frac{\sin \omega\tau/2}{\omega^2} \tag{3-3}$$

here ω is the radial frequency = $2\pi\upsilon$, υ is the frequency, and $j^2 = -1$. Clearly the $1/\omega^2$ factor restricts the spectrum to a narrow, low frequency range.

<u>Method of Differentiation Illustrated with the Straight Line</u>

The velocity spectrum of any transform of (x, t) data is simply the product of the spectrum of the (x, t) data multiplied by $j\omega$.[8] Consequently, the transform of the artificial velocity data can be obtained from Equation (3-3).

$$\Im\left(\frac{dx}{dt}\right) = j\omega\,\Im(x) = \frac{2V}{\sqrt{2\pi}} \frac{\sin \omega\tau/2}{\omega} \tag{3-4}$$

The term $\{\sin \omega\tau/2\}/\omega$ is identical to the spectrum of a square pulse of duration τ. Of course $\Im(dx/dt)$ <u>is</u> the spectrum of a wave of constant velocity V because we originally specified a straight line of constant slope V.

TABLE 3-1. NERD FILTER PARAMETERS FOR THE MEASURED STREAK DATA

Constant	Value	Description
β	0.025	Relative pass bandwidth, e.g., 0.45 MHz for #E674
δ	0.05	Relative width of transition from pass to stop band, e.g., 0.9 MHz for #E674
ϵ	0.01	Allowable error (due to Gibb's oscillation[8]) introduced by filter

CHOICE OF NERD FILTER CHARACTERISTICS FOR THE MEASURED STREAK DATA

The spectrum of the unfiltered or raw velocity $U_S(t)$ data was needed to choose the filter's characteristics. A rudimentary differentiation of the (x, t) data was performed using the finite-difference method to obtain $U_S(t)$, Equation (3-5). These velocity data were only used to choose the filter parameters, not for the ELSGT calibration, where x_t is the x value at time t and δt is the time increment.

$$U_s(t) = \left(\frac{dx}{dt}\right)_t \approx \frac{x_{t+\delta t} - x_t}{\delta t} \tag{3-5}$$

The spectrum of these raw shock velocity data, $\Im(dx/dt)$ or $\Im(U_S)$, was obtained by the fast Fourier transform (FFT) method. The unfiltered velocity data are plotted against time in Figure 3-2; and the logarithmic velocity spectrum is shown in Figure 3-3 for the same data; the spectrum is scaled by $1/\sqrt{(2\pi)}$ as in Equation (3-2). The amplitude of the logarithmic spectrum falls rapidly by two orders of magnitude between 0 and 0.41 MHz, i.e., to 1 percent of the zero frequency magnitude.

CHOICE OF FILTER BANDWIDTH, β

The spectrum of Figure 3-3 shows that no useful information can be obtained above 0.45 MHz as the data is too noisy. The frequency of 0.45 MHz corresponds to $\beta = 0.025$ or 1/40th of the full or Nyquist bandwidth. (The Nyquist limit F_{max} is related to the sampling interval δt by $F_{max} = 1 / 2\delta t$). Consequently a value of $\beta = 0.025$ was chosen; this rejects most of the noisy data while maintaining the true streak data; see below.

The NERD filter essentially multiplies the spectrum of the (x, t) data by $j\omega$ for frequencies from zero up to the relative cut-off frequency β, and attenuates all data above β.

VELOCITY RESULTS

Filter

The filter was thus chosen to have the characteristics shown in Table 3-1. The data are filtered by convolution with a filter function as shown in Equation (3-1).

The results for all three experiments are shown in Figure 3-4. The U_S data fluctuate and it can be seen that, at distances greater than 100 mm ($t > 24\ \mu s$), the precision is significantly reduced. The reduced precision is caused by the low image contrast, at the streak edge, at pressures less than 1 GPa; this results from a combination of a smaller rate of change of pressure in the shock front (dp/dx) and a smaller change in refractive index. Note that the longitudinal wave velocity in PMMA is 2.7 km/s; all the velocities in Figure 3-4 exceed 3.1 km/s and therefore represent a shock wave.

Because the x_i data are filtered over points $i - (1-N_p)$ to $i + N_p$ then (N_p-1) and N_p, points at the beginning and end of the x data cannot be differentiated. N_p depends on the degree of filtering, e.g., if $\delta = 0.05$ and $\epsilon = 0.01$ then $N_p = 45$, for $\delta = 0.2$ and $\epsilon = 0.01$ then $N_p = 11$; see Appendix C.

Correction for Numerical Shift

The NERD routine calculates the velocity mid-way between each pair of points. Thus, the velocity data are thus shifted by half the sampling interval (25 μm $\div$ magnification in this work). This small effect can often be ignored, however, corrections have been made for this effect in the following velocity data.

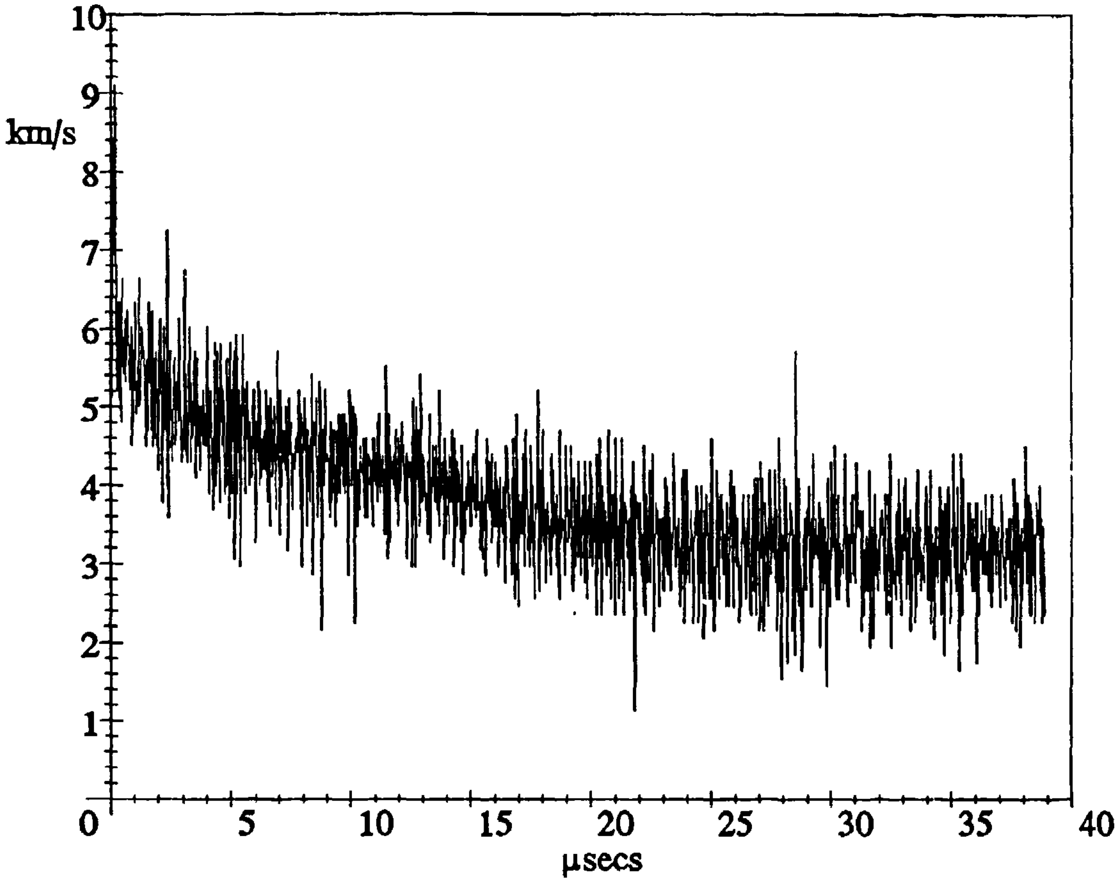

FIGURE 3-2. UNFILTERED SHOCK VELOCITY DATA VS. TIME

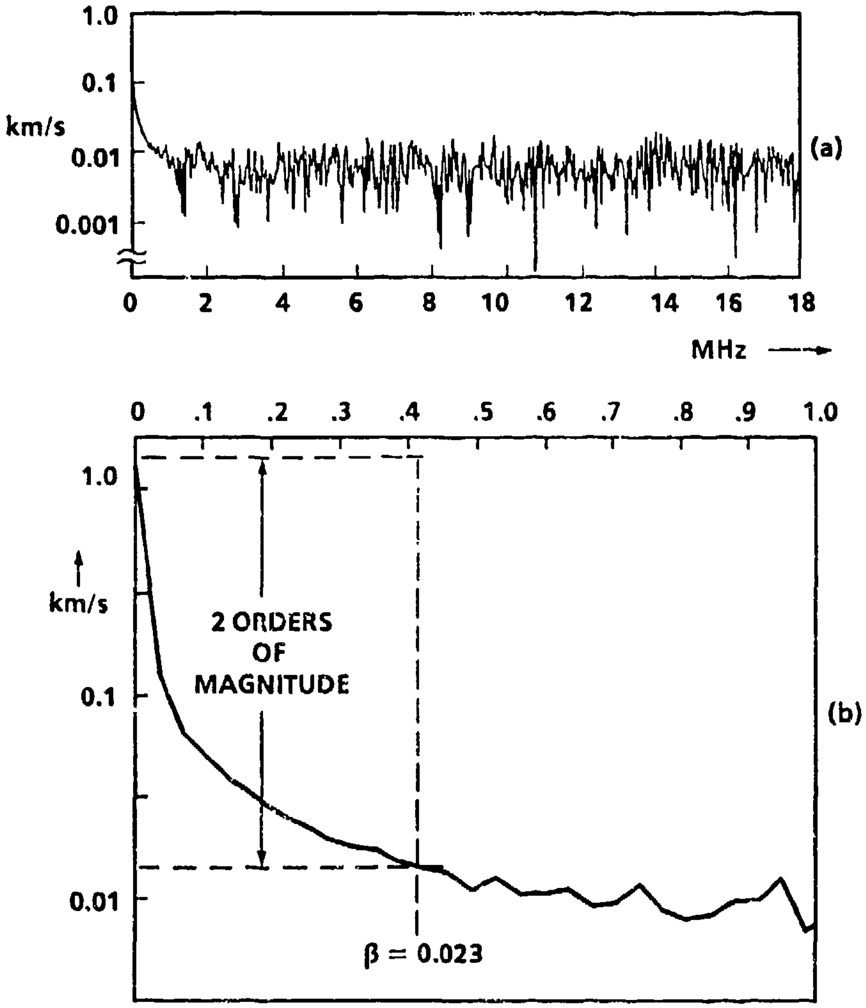

FIGURE 3-3. LOGARITHMIC SPECTRUM OF UNFILTERED VELOCITY DATA
(a) FULL SPECTRUM, 0 TO 18 MHz;
(b) EXPANDED SPECTRUM, 0 TO 1 MHz

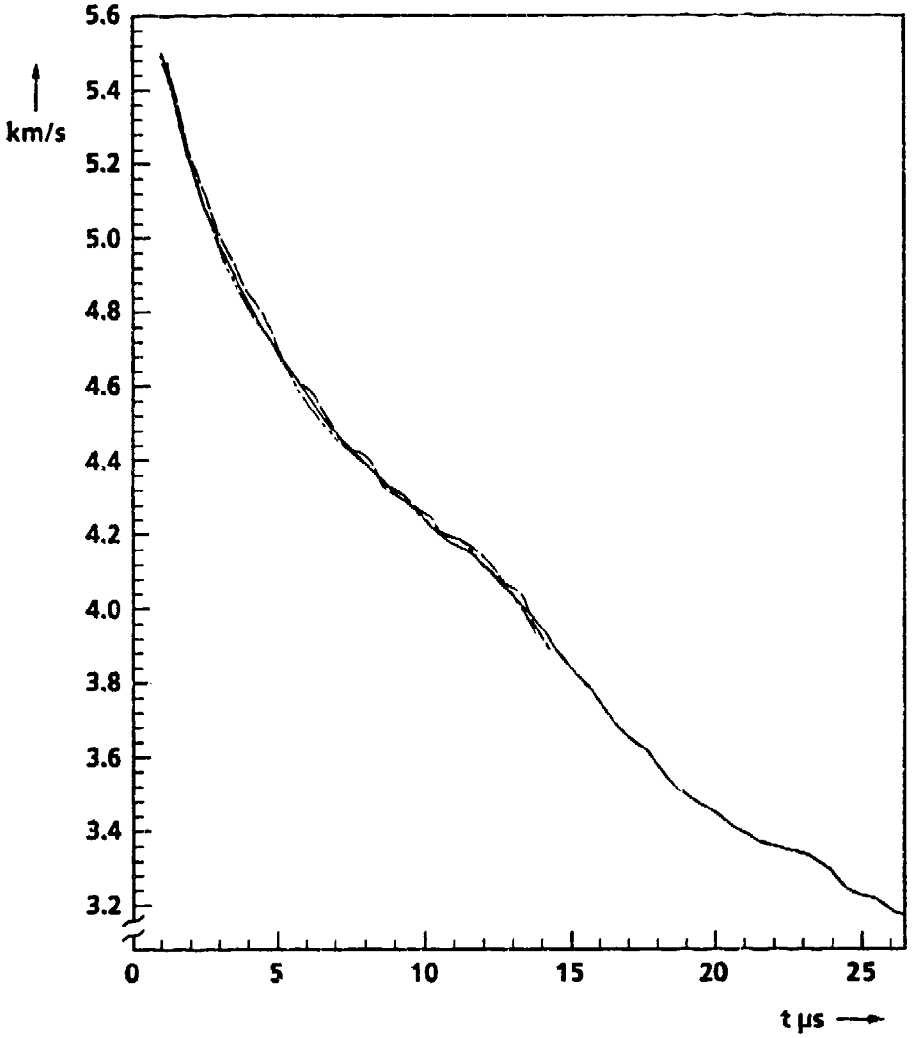

FIGURE 3-4. SHOCK VELOCITY DATA OBTAINED USING NERD FILTER FOR THREE EXPERIMENTS

PARTICLE VELOCITY CALCULATION

The particle velocities, u_p, were obtained from the U_S data by solution of the Hugoniot equations of Erkman;[2] these are:

For $0.03 \le u_p \le 0.5363$ *km/s*:

$$U_s = 2.7228 + 4.0667u_p - 10.9051u_p^2 + 10.6912u_p^3 \tag{3-6}$$

For $u_p \ge 0.5363$ *km/s*:

$$U_s = 2.561 + 1.595u_p \tag{3-7}$$

The polynomial Equation (3-6) was solved by Newton's approximation for each point below 0.5363 km/s; the numerical accuracy was 1 part in 10^8. The linear Equation (3-7) was solved exactly.

The results for all three experiments are shown in Figure 3-5. It is seen that there is an apparent discontinuity in the data in the region where $u_p = 0.5$ km/s and $U_S = 3.3$ km/s. This is due to the pronounced curvature in the PMMA Hugoniot at these velocities and not to errors in the raw data; it is a real discontinuity in the U_S-u_p relationship.

Errors in PMMA Hugoniot

As will be seen later, only Equation (3-7) was necessary for the final calibration. This equation fits the data of Barker and Hollenbach,[9] and Shuler and Nunziato[10] with a standard deviation (SD) of 11 m/s in particle velocity for any given shock velocity in the range from 3.3 to 5.6 km/s.

Pressure Calculation, the ELSGT Calibration Data

The final results were obtained for three individual calibration experiments by the use of Equation (1-1) for a density $\rho_0 = 1186$ kg/m^3. The results are shown in Figures 3-6 and 3-7 for pressure versus time and distance. The data were averaged between 9 and 70 mm for the three experiments.

The distances shown in Figure 3-7 were obtained using the (x, t) data of Figure 3-1. The distances shown have been reduced for the numerical shift (described on Page 3-5). The correction is 25 μm $\div$ magnification, i.e., 35 μm and 71 μm for the 70 mm and 150 mm experiments. The results are tabulated as pressure versus distance data in Table 3-2. For convenience, the Table 3-2 data have been interpolated to distance increments of 0.25 mm.

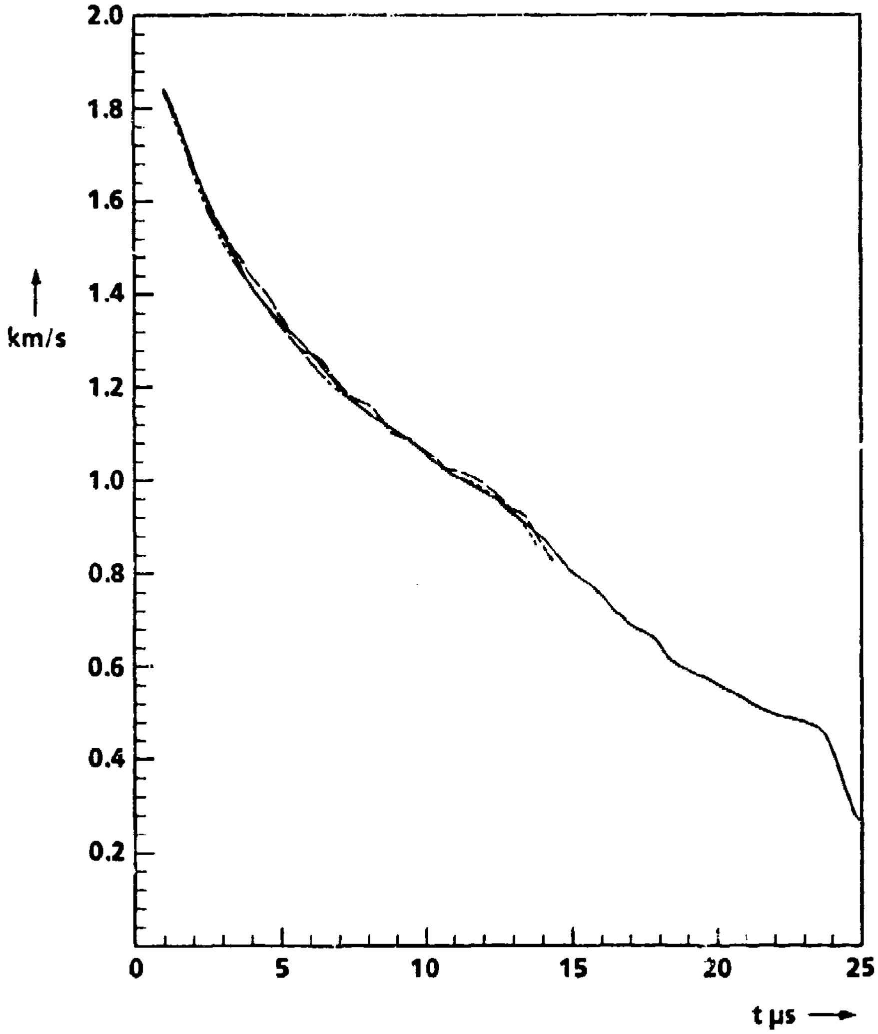

FIGURE 3-5. CALCULATED PARTICLE VELOCITIES

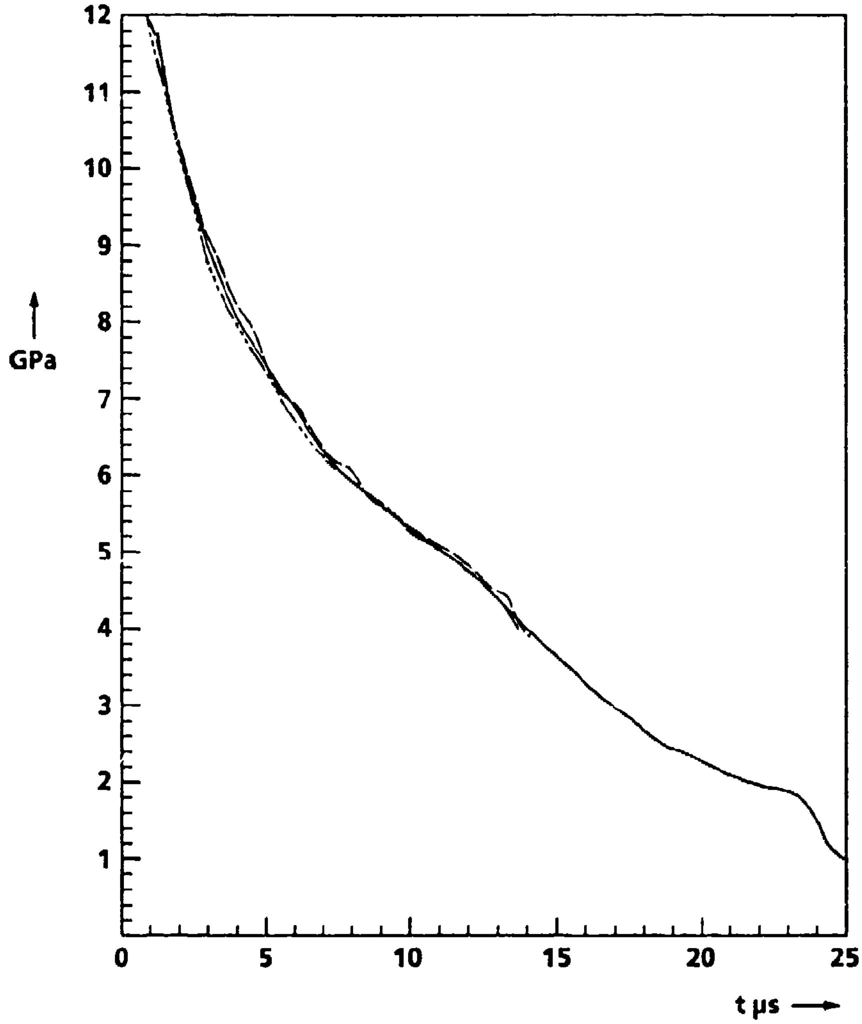

FIGURE 3-6. RESULTS OF ELSGT CALIBRATION, PRESSURE VS. TIME, FOR ALL THREE EXPERIMENTS

As described earlier the data are not considered reliable for $x > 100$ mm, $t > 24$ μs, for two reasons: the difficulty in reading the weak traces and the uncertainty of the PMMA shock Hugoniot for $u_p < 0.5$ km/s.

INDEPENDENT VERIFICATION OF PRESSURE CALCULATIONS

These pressure data were independently verified by Sandusky and Groves[11] at NSWCDD. They read the photographic records of this work using a different trace-reading apparatus than the one described here. Subsequently, they reduced the data to shock velocity, particle velocity, and pressure using spline-fitting techniques. The results are shown in Appendix D.

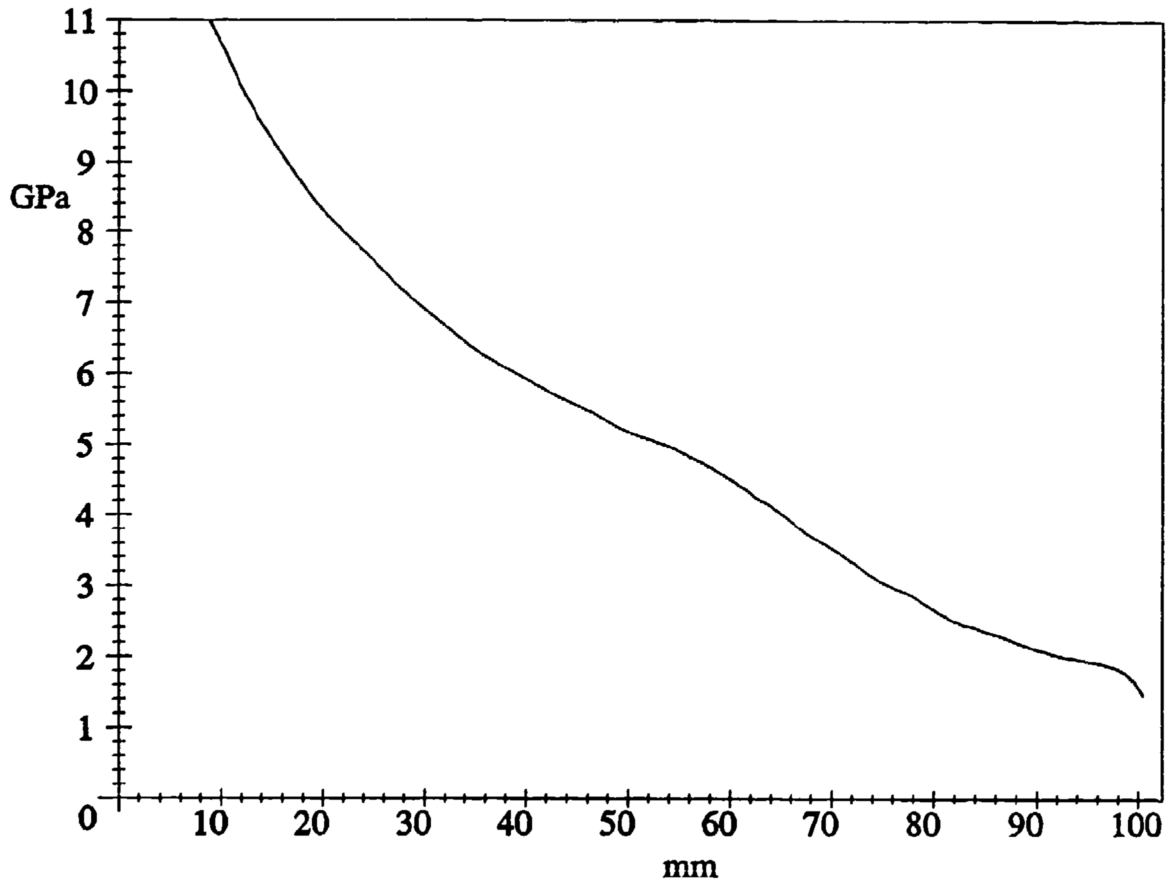

FIGURE 3-7. RESULTS OF ELSGT CALIBRATION, PRESSURE VS. DISTANCE, DATA AVERAGED OVER THREE EXPERIMENTS

TABLE 3-2. NSWC ELSGT CALIBRATION DATA, PRESSURE $P_{(x)}$ VERSUS DISTANCE x, 9 TO 100 mm, AT 0.25 mm INCREMENTS

x mm	$P_{(x)}$ GPa	$P_{(x+.25)}$ GPa	$P_{(x+.5)}$ GPa	$P_{(x+.75)}$ GPa	x mm	$P_{(x)}$ GPa	$P_{(x+.25)}$ GPa	$P_{(x+.5)}$ GPa	$P_{(x+.75)}$ GPa
9.00	10.96	10.89	10.81	10.74	**55.00**	4.91	4.89	4.87	4.85
10.00	10.67	10.59	10.52	10.43	**56.00**	4.83	4.81	4.79	4.78
11.00	10.35	10.28	10.21	10.14	**57.00**	4.76	4.74	4.72	4.70
12.00	10.06	9.99	9.92	9.85	**58.00**	4.68	4.66	4.64	4.62
13.00	9.79	9.73	9.66	9.61	**59.00**	4.60	4.58	4.56	4.53
14.00	9.55	9.49	9.43	9.37	**60.00**	4.51	4.49	4.46	4.44
15.00	9.31	9.26	9.20	9.15	**61.00**	4.41	4.39	4.37	4.34
16.00	9.10	9.04	8.99	8.93	**62.00**	4.31	4.28	4.26	4.24
17.00	8.88	8.82	8.77	8.73	**63.00**	4.22	4.19	4.17	4.15
18.00	8.67	8.63	8.58	8.53	**64.00**	4.13	4.10	4.08	4.05
19.00	8.48	8.44	8.39	8.35	**65.00**	4.02	4.00	3.97	3.94
20.00	8.31	8.27	8.23	8.18	**66.00**	3.91	3.88	3.86	3.83
21.00	8.14	8.11	8.07	8.03	**67.00**	3.80	3.78	3.75	3.72
22.00	8.00	7.96	7.93	7.89	**68.00**	3.70	3.68	3.66	3.63
23.00	7.86	7.83	7.79	7.76	**69.00**	3.61	3.59	3.57	3.55
24.00	7.72	7.69	7.66	7.62	**70.00**	3.53	3.51	3.48	3.46
25.00	7.58	7.55	7.51	7.48	**71.00**	3.43	3.41	3.39	3.37
26.00	7.44	7.40	7.37	7.33	**72.00**	3.34	3.31	3.29	3.26
27.00	7.30	7.26	7.23	7.19	**73.00**	3.23	3.20	3.18	3.15
28.00	7.16	7.13	7.09	7.06	**74.00**	3.13	3.11	3.09	3.07
29.00	7.03	7.00	6.97	6.94	**75.00**	3.05	3.03	3.01	3.00
30.00	6.91	6.88	6.85	6.82	**76.00**	2.98	2.96	2.95	2.93
31.00	6.79	6.77	6.74	6.71	**77.00**	2.92	2.90	2.89	2.87
32.00	6.68	6.65	6.62	6.59	**78.00**	2.85	2.83	2.80	2.78
33.00	6.57	6.54	6.51	6.48	**79.00**	2.76	2.74	2.71	2.69
34.00	6.45	6.42	6.40	6.37	**80.00**	2.66	2.64	2.61	2.59
35.00	6.34	6.32	6.29	6.27	**81.00**	2.57	2.55	2.53	2.51
36.00	6.25	6.23	6.20	6.18	**82.00**	2.50	2.48	2.47	2.45
37.00	6.16	6.14	6.12	6.10	**83.00**	2.44	2.43	2.42	2.41
38.00	6.08	6.07	6.05	6.03	**84.00**	2.40	2.39	2.38	2.37
39.00	6.01	5.99	5.97	5.96	**85.00**	2.36	2.35	2.34	2.33
40.00	5.94	5.92	5.90	5.88	**86.00**	2.31	2.30	2.29	2.27
41.00	5.86	5.83	5.81	5.79	**87.00**	2.26	2.25	2.23	2.22
42.00	5.77	5.75	5.73	5.71	**88.00**	2.20	2.19	2.18	2.16
43.00	5.69	5.67	5.66	5.64	**89.00**	2.15	2.14	2.13	2.11
44.00	5.62	5.61	5.59	5.57	**90.00**	2.10	2.09	2.08	2.07
45.00	5.56	5.54	5.53	5.51	**91.00**	2.06	2.05	2.04	2.03
46.00	5.49	5.47	5.45	5.44	**92.00**	2.02	2.02	2.01	2.00
47.00	5.42	5.39	5.38	5.35	**93.00**	1.99	1.99	1.98	1.97
48.00	5.33	5.31	5.29	5.27	**94.00**	1.96	1.96	1.95	1.94
49.00	5.25	5.23	5.22	5.20	**95.00**	1.94	1.93	1.93	1.92
50.00	5.18	5.17	5.15	5.14	**96.00**	1.91	1.91	1.90	1.89
51.00	5.13	5.11	5.10	5.09	**97.00**	1.88	1.87	1.86	1.84
52.00	5.08	5.07	5.06	5.04	**98.00**	1.82	1.81	1.79	1.76
53.00	5.03	5.02	5.00	4.99	**99.00**	1.73	1.69	1.66	1.62
54.00	4.98	4.96	4.94	4.93	**100.00**	1.57			

CHAPTER 4

ERROR ANALYSIS

RELATIONSHIP BETWEEN ERRORS IN SHOCK VELOCITY AND PRESSURE

For the calibrated range (9 to 100 mm) the linear Hugoniot of Equation (3-7) can be used. This is combined with Equation (1-1) to obtain pressure in terms of U_S.

$$U_s = a + bu_p,$$
$$and\ P = \rho_0 U_s \frac{(U_s - a)}{b} \qquad (4\text{-}1)$$

From conventional error analysis the standard deviation (SD) in pressure, δP, can be expressed in terms of the deviations in shock velocity, δU_S, and particle velocity, δu_p. Because u_p is obtained directly from U_S using Equation (3-7) the two deviations are added, i.e., they are dependent variables. The deviation in U_S consists of the combined effects of: the error in position (due to optical misalignment); the error due to numerical differentiation of noisy data by the NERD technique; and the systematic error introduced by the finite width of the camera slit.

$$\frac{\delta P}{P} \approx \frac{\delta U_s}{U_s} + \frac{\delta u_p}{u_p} \qquad (4\text{-}2)$$

Combining equations we obtain the deviation in pressure solely due to deviation in the shock velocity,

$$\frac{\delta P}{P} \approx \frac{(2U_s - a)}{U_s - a}\,\frac{\delta U_s}{U_s} \qquad (4\text{-}3)$$

However, for independent variables the <u>variance</u> of the result, P here, would be obtained from the sum of the variances of the independent factors. Consequently, the errors due to the calculation of u_p from the Hugoniot, δu_p, are treated as independent errors, see below.

Numerical Errors in Calculating U_S with the NERD Filter

The numerical errors introduced by measurement of the streak record depend on the sharpness of the edge of the photographic image. These errors are obvious in Figure 3-2.

To estimate the error, an artificial streak record, with a velocity of 4 km/s and the same optical magnification, was modified by the addition of numerical noise; the result differentiated. The SD of the added noise n(t) was set equal to the measured SD of the real data. The SD was estimated by reading 10 points on the trace, 30 times each. The points were read in sequence, i.e., 1, 2, 3, 4, ... , 10, 1, 2, 3, 4, ... etc. The trace reader carriage was moved to each x (time) position in turn then the y (distance) value was measured. The mean SD for the 10 points between 0 and 100 mm was 5.0 μm, with a standard error of 0.3 μm. Above 100 mm, the SD increased to 8.5 μm.

A value of 5.0 μm was used as the SD of the measured data from the true streak data, for the calibration range of 9 to 100 mm. Therefore, a noise signal n(t) of SD 5.0 μm was added to the artificial streak x = Vt.

$$x = Vt + n(t) \quad for \ \frac{-\tau}{2} < t < \frac{\tau}{2} \tag{4-4}$$

The NERD filter technique, with the same values of β, δ, and ϵ as in Table 3-1, was used to differentiate these artificial (x, t) data. The results are presented in Table 4-1.

TABLE 4-1. RESULTS OF DIFFERENTIATING ARTIFICIAL STREAK RECORD

True mean velocity, V	4 km/s
Mean velocity calculated with NERD differential method	3.99988 km/s
SD of differentiated data, σ	2.76 m/s
Number of points	1312

Assuming that the errors in trace reading are random and normally distributed, then the error in shock velocity $\delta U_S \approx 2.76$ m/s, and would be $< 3.29\sigma$ (9.08 m/s) for 99.9 percent of the calculated velocity data. These estimates do not include the other errors described elsewhere.

Errors in U_S Due to Optical Alignment of PMMA/Pentolite Interface

The greatest error in optical alignment probably was due to the positioning of the PMMA/pentolite interface. Care was taken to place the interface at the x = 0 position. However, it is likely that there was an error in the position of $\delta x \approx 0.2$ mm. This would lead to an error in shock velocity, δU_S depending on the value of U_S, i.e., $\delta U_S = \delta x \, dU_S/dx$. The dU_S/dx term can be obtained from the U_S data as functions of time using

$$\frac{dU_S}{dx} = \frac{dU_S}{dt}\frac{dt}{dx} = \frac{1}{U_s}\frac{dU_S}{dt} \tag{4-5}$$

These errors are summarized in Table 4-2 and are also incorporated into the error analysis summarized in Table 4-4.

TABLE 4-2. ERRORS IN SHOCK VELOCITY DUE TO POSITION UNCERTAINTY

x mm	dU_S/dx (m/s)/mm	δU_S m/s
9	-57.2	11.4
40	-16.5	3.3
70	-24.3	4.9
100	-11.3	2.3

Errors Due to the Hugoniot

The SD of u_p data has been obtained by comparing the predictions of Equation (3-7) with the published data of Shuler and Nunziato.[9] The SD of the Equation 3-7 fit from the original u_p data was found to be 11 m/s. The uncertainty of the u_p data was 1 percent.

Other Errors

The total experimental errors due to focus, alignment in trace reading, etc., are estimated to be less than 0.1 percent. The width of the streak camera slit was 200 μm. This width introduced a random numerical error in trace reading. This random error is treated in the next section. The error in measurement of camera writing speed was less than 0.01 percent. We attempted to measure the tilt of the slit relative to the time axis, i.e., the deviation from 90°, by recording an image of the slit on a static photograph. The deviation was too small to measure with the trace reading equipment; the error is therefore less than 0.01 percent. All of these random errors are small in comparison to the numerical errors introduced by the differentiation of the raw (x, t) data, the errors in position x, and the errors of the shock Hugoniot for PMMA, i.e., a and b of Equation (4-1). The slit width also introduced a systematic error, this is estimated to be a maximum of 0.6 percent and typically 0.3 percent.

Errors in Pressure

The combined errors in pressure can now be obtained. With a = 2.561 km/s from Equation (3-7) we can solve Equation (4-3) to obtain K, where $K = (2U_S - a)/(U_S - a)$, and the resulting errors, δP, are shown in Table 4-3. The error δU_S was taken as the combined deviation due to the NERD method (2.76 m/s), the slit error (0.3 percent), and the position error data from Table 4-2. The error δu_p was the combined error of the fit to the Hugoniot data (11 m/s) and the uncertainty of the Hugoniot data (1 percent).

TABLE 4-3. ERRORS IN PRESSURE DUE TO ERRORS IN U_S AND u_p

x mm	U_S km/s	K	P GPa	δP MPa
9	5.346	2.920	10.96	244
40	4.385	3.404	5.94	141
70	3.814	4.044	3.53	106
100	3.296	5.484	1.57	64

These errors are summarized in Table 4-4.

Averaging over the Three Experiments

Between 9 and ≈70 mm the results of three traces have been averaged; this improves the accuracy of the estimate of the true shock velocity. In other words the standard error, σ_x, of the average at each position x is estimated from the variance of the sum of the individual results and n, the number of independent measurements, here n = 3.

$$\sigma_x^2 = \frac{\sum_n \delta U_s^2(x)}{n\sqrt{n-1}} \tag{4-6}$$

TABLE 4-4. TOTAL ERRORS IN PRESSURE DUE TO ERRORS IN POSITION, HUGONIOT, AND U_S FOR THE AVERAGE OF THREE EXPERIMENTS

x mm	P GPa	δP mean MPa	δP/P mean %
9	10.96	173	1.57
40	5.94	100	1.69
70	3.53	75	2.12
100	1.57	64	4.06

ERRORS SUMMARY

Table 4-4 summarizes the random error calculations. Assuming the errors are normally distributed, 99.9 percent of all pressure data will have errors less than 3.29 times the δP/P value. The 'δP mean' column shows the most likely (or standard) error obtained by summing the variances and correcting the value for the number of observations, i.e., adjusting the value of Equation (4-2) to between 9 and 70 mm.

From Table 4-4 we conclude that the pressure error (expressed as a standard deviation) due to errors in position, Hugoniot, slit width, and U_S, is likely to be between 1.6 and 4.1 percent.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The calibration described here is based on a careful measurement of the velocity of the shock U_S propagated into the PMMA gap. The particle velocity u_p was obtained from published experimental shock Hugoniot data that relate u_p to U_S.[9] The pressure corresponding to U_S was then calculated using the relationship between U_S and pressure, Equation (1-1).

The shock velocity U_S data presented here are believed to be of the highest precision and accuracy. The particle velocity data and thus the pressure calibration data are influenced by the choice of the shock Hugoniot used. The likely inaccuracies of these pressure data due to the choice of Hugoniot are presented.

The estimated mean error of the pressure calibration is between 1.6 and 4.1 percent between 9 and 100 mm of PMMA attenuator distance. These errors are due largely to the method of estimating particle velocity, i.e., from the measured shock velocity and published Hugoniot data. The uncertainty of calculating shock velocity with the NERD method is remarkably small, it is estimated to be 2.76 m/s or roughly 0.05 percent (excluding the errors slit width, optical alignment, etc.).

The results should be verified by conducting direct particle velocity and pressure measurements, using ***in situ*** gauges at discrete positions in the PMMA gap.

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APPENDIX A

IMAGE DISTORTION DUE TO REFRACTION IN THE PMMA CYLINDER

Consider an object of length OA or x located on the axis of the PMMA cylinder; see Figure A-1. This object represents the tip of the shock wave on the axis of the PMMA cylinder that is observed with the streak camera. The center O is on the projection of the optic axis from the camera lens. This object is viewed through the radius of the PMMA cylinder, i.e., the thickness r. The refraction of light in the PMMA alters the apparent distance between the lens axis and the object, i.e., the object distance d. The apparent length of the object, as seen by the camera, becomes OA′ or x′.

Let the refractive index of the PMMA be n and the image displacement due to refraction be $\delta x = x' - x$. If i and i′ are the angles subtended by the object and image in Figure A-1 then it can be shown that

$$\delta x = r(\tan i' - \tan i)$$

$$\sin i' = \frac{x'}{\sqrt{x'^2 + d^2}}$$

$$\textit{and} \quad n = \frac{\sin i'}{\sin i} \quad \textit{Snell's law}$$

If the angles are small then sin i′ ≈ tan i ≈ i, hence

$$\tan i' = \frac{x'}{d}$$

$$\sin i = \frac{x'}{n\sqrt{x'^2 + d^2}} \approx \frac{x'}{nd} \approx \tan i$$

$$\textit{so} \quad \frac{\delta x}{x} \approx \frac{\delta x}{x'} \approx \frac{r}{d}\left(1 - \frac{1}{n}\right)$$

For r = 47 mm, d = 2.4 m, n = 1.49 then $\delta x/x = 0.0065$, i.e., 0.65%. Note that this distortion occurs with any type of illumination, even with a collimated light source.

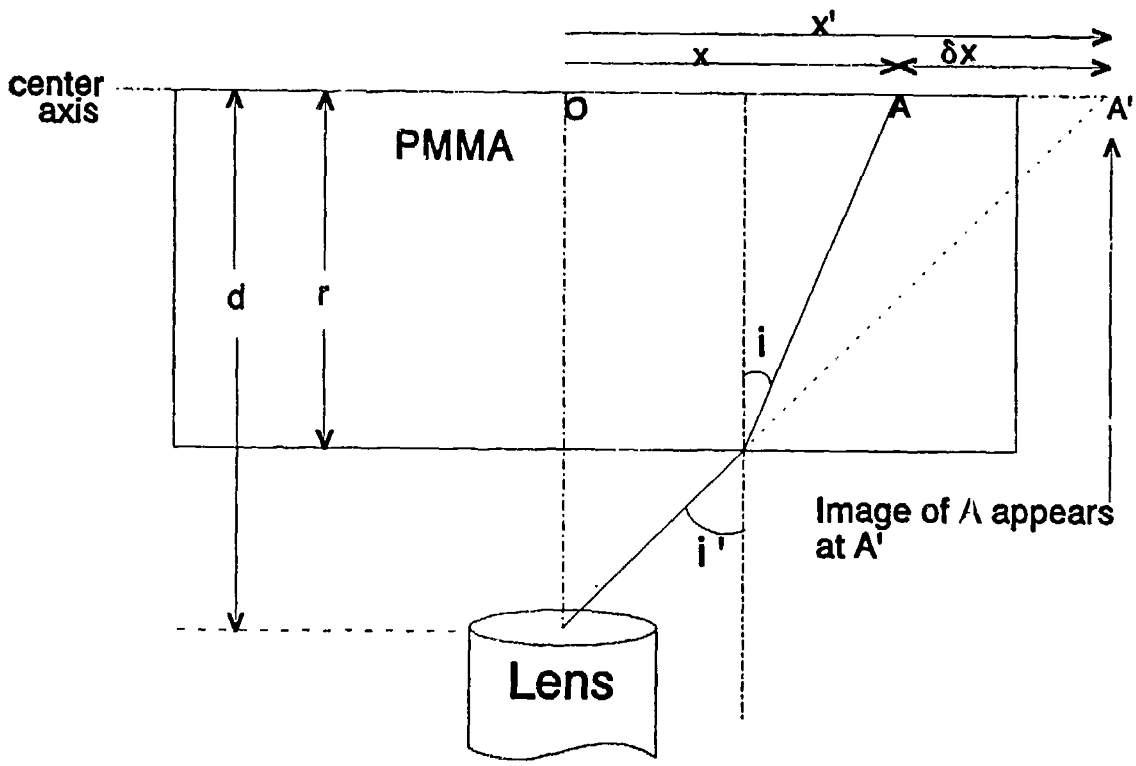

FIGURE A-1. REFRACTION OF STREAK IMAGE THROUGH PMMA CYLINDER

APPENDIX B

RAW DATA

The following tables represent the original data generated in this study. The (x, t) data are the original data as read from the photographic records. The (x, t) data were converted to time and distance, using the camera speed and optical magnification, prior to printing. The U_s, u_p, and P data are the results of employing the computational techniques described in this report.

To read these tables note that not all the time values have been printed. The times in the left hand column match the data in the next column to the right. The times for the remaining nine columns can be obtained because the time increment is a constant. The time increment is printed at the top of each table, as are the units for each set of data, e.g., mm, km/s, GPa. The dashes at the top of the U_s, u_p, and P represent those (N_p - 1) data points that cannot be calculated with the NERD filter technique.

TABLE B-1. E673 CALIBRATION DATA, (x, t), DISTANCE VS. TIME

Time increment = 27.7515 ns
Number of points = 549

μs	<——— Units: mm ———>									
0.000	0.000	0.068	0.191	0.360	0.524	0.655	0.804	0.970	1.076	1.263
0.278	1.451	1.641	1.783	1.927	2.085	2.235	2.387	2.523	2.692	2.858
0.555	3.016	3.163	3.314	3.471	3.628	3.807	3.961	4.108	4.306	4.439
0.833	4.609	4.725	4.903	5.050	5.215	5.367	5.528	5.670	5.812	5.963
1.110	6.104	6.255	6.420	6.607	6.758	6.926	7.043	7.204	7.349	7.473
1.388	7.669	7.802	7.960	8.124	8.267	8.431	8.563	8.723	8.857	9.003
1.665	9.137	9.288	9.421	9.589	9.729	9.905	10.058	10.191	10.328	10.476
1.943	10.603	10.784	10.924	11.078	11.229	11.383	11.510	11.681	11.798	11.954
2.220	12.081	12.211	12.373	12.500	12.666	12.791	12.958	13.108	13.242	13.378
2.498	13.526	13.653	13.786	13.951	14.083	14.218	14.352	14.496	14.643	14.789
2.775	14.971	15.105	15.235	15.368	15.516	15.659	15.769	15.922	16.060	16.166
3.053	16.330	16.477	16.594	16.771	16.891	17.038	17.185	17.329	17.476	17.596
3.330	17.734	17.856	17.981	18.118	18.247	18.405	18.537	18.669	18.812	18.918
3.608	19.078	19.216	19.349	19.489	19.657	19.783	19.896	20.018	20.180	20.307
3.885	20.438	20.585	20.730	20.853	20.986	21.127	21.256	21.404	21.530	21.649
4.163	21.813	21.909	22.051	22.164	22.297	22.451	22.577	22.705	22.830	22.962
4.440	23.081	23.231	23.373	23.484	23.636	23.756	23.916	24.044	24.162	24.297
4.718	24.440	24.566	24.697	24.838	24.957	25.091	25.237	25.347	25.481	25.629
4.995	25.747	25.877	25.990	26.138	26.267	26.412	26.558	26.686	26.830	26.929
5.273	27.072	27.185	27.291	27.453	27.568	27.686	27.809	27.969	28.089	28.213
5.550	28.380	28.486	28.617	28.743	28.864	28.999	29.141	29.274	29.394	29.530
5.828	29.657	29.770	29.887	30.021	30.151	30.273	30.386	30.533	30.667	30.787
6.105	30.906	31.003	31.150	31.259	31.411	31.517	31.642	31.774	31.886	32.029
6.383	32.159	32.291	32.413	32.554	32.677	32.811	32.936	33.053	33.184	33.303
6.660	33.407	33.553	33.676	33.814	33.920	34.045	34.178	34.309	34.427	34.570
6.938	34.696	34.805	34.913	35.042	35.177	35.302	35.429	35.535	35.668	35.799
7.215	35.909	36.025	36.159	36.310	36.421	36.521	36.637	36.779	36.897	37.031
7.493	37.155	37.282	37.404	37.527	37.650	37.761	37.894	38.015	38.131	38.254
7.770	38.369	38.486	38.626	38.727	38.850	38.982	39.092	39.202	39.338	39.475
8.048	39.609	39.719	39.842	39.956	40.054	40.205	40.339	40.459	40.592	40.705
8.325	40.858	40.965	41.096	41.192	41.310	41.431	41.551	41.674	41.790	41.895
8.603	42.051	42.152	42.272	42.392	42.518	42.643	42.746	42.865	42.985	43.119
8.880	43.228	43.354	43.477	43.601	43.724	43.867	43.974	44.088	44.192	44.319
9.158	44.450	44.559	44.692	44.793	44.906	45.035	45.151	45.275	45.405	45.517
9.436	45.644	45.762	45.877	45.987	46.094	46.234	46.368	46.497	46.606	46.734
9.713	46.837	46.945	47.062	47.185	47.322	47.428	47.530	47.662	47.782	47.915
9.991	48.032	48.151	48.261	48.386	48.501	48.637	48.740	48.846	48.982	49.092
10.268	49.202	49.322	49.441	49.564	49.675	49.814	49.935	50.040	50.174	50.267
10.546	50.379	50.499	50.618	50.743	50.849	50.951	51.057	51.164	51.298	51.423
10.823	51.536	51.649	51.776	51.914	51.982	52.112	52.235	52.334	52.447	52.590
11.101	52.698	52.800	52.930	53.071	53.182	53.307	53.415	53.535	53.636	53.742
11.378	53.895	54.008	54.127	54.242	54.367	54.457	54.552	54.694	54.839	54.944
11.656	55.050	55.165	55.268	55.382	55.522	55.628	55.723	55.849	55.974	56.082
11.933	56.213	56.337	56.433	56.538	56.658	56.757	56.856	56.959	57.097	57.198
12.211	57.335	57.438	57.568	57.682	57.794	57.907	58.025	58.140	58.266	58.374
12.488	58.507	58.607	58.720	58.821	58.927	59.040	59.161	59.250	59.377	59.483
12.766	59.595	59.716	59.831	59.941	60.050	60.161	60.286	60.433	60.540	60.659
13.043	60.765	60.889	60.986	61.105	61.193	61.314	61.424	61.537	61.669	61.775
13.321	61.883	61.988	62.099	62.211	62.334	62.448	62.557	62.665	62.763	62.859
13.598	62.971	63.105	63.215	63.324	63.434	63.555	63.682	63.776	63.884	63.985
13.876	64.113	64.203	64.312	64.440	64.541	64.661	64.769	64.873	64.950	65.073
14.153	65.197	65.291	65.391	65.481	65.620	65.733	65.856	65.948	66.059	66.162
14.431	66.271	66.376	66.494	66.610	66.717	66.819	66.931	67.020	67.119	67.232
14.708	67.342	67.470	67.585	67.691	67.781	67.874	67.983	68.089	68.167	68.285
14.986	68.415	68.507	68.619	68.694	68.801	68.839	68.915	68.992	69.116	

TABLE B-2. E674 CALIBRATION DATA, (x, t), DISTANCE VS. TIME

Time increment = 27.7885 ns
Number of points = 1401

μs	Units: mm									
0.000	0.000	0.082	0.290	0.432	0.664	0.863	1.056	1.309	1.519	1.684
0.278	1.843	1.988	2.164	2.206	2.482	2.630	2.769	2.902	3.087	3.246
0.556	3.402	3.552	3.717	3.888	4.035	4.194	4.367	4.532	4.697	4.853
0.834	4.998	5.157	5.324	5.449	5.614	5.748	5.907	6.051	6.227	6.381
1.112	6.517	6.665	6.804	6.943	7.128	7.292	7.431	7.573	7.724	7.891
1.389	8.056	8.212	8.371	8.525	8.678	8.806	8.931	9.087	9.218	9.394
1.667	9.550	9.697	9.845	9.976	10.149	10.274	10.405	10.561	10.689	10.848
1.945	10.995	11.151	11.276	11.421	11.538	11.638	11.858	12.003	12.159	12.265
2.223	12.407	12.574	12.719	12.850	13.000	13.148	13.258	13.460	13.559	13.707
2.501	13.849	14.008	14.147	14.267	14.397	14.531	14.681	14.837	14.962	15.090
2.779	15.238	15.385	15.533	15.666	15.837	15.990	16.127	16.260	16.379	16.504
3.057	16.640	16.765	16.953	17.075	17.225	17.348	17.467	17.592	17.734	17.901
3.335	18.055	18.188	18.307	18.455	18.589	18.716	18.861	19.020	19.137	19.250
3.613	19.404	19.560	19.685	19.818	19.957	20.074	20.193	20.332	20.471	20.596
3.890	20.741	20.866	21.002	21.127	21.252	21.420	21.545	21.704	21.837	21.945
4.168	22.078	22.223	22.362	22.493	22.618	22.720	22.842	23.004	23.146	23.257
4.446	23.376	23.535	23.669	23.780	23.933	24.038	24.200	24.347	24.492	24.617
4.724	24.762	24.895	25.003	25.125	25.245	25.355	25.512	25.654	25.790	25.889
5.002	26.023	26.185	26.304	26.412	26.557	26.687	26.846	26.931	27.045	27.210
5.280	27.318	27.474	27.599	27.721	27.866	27.948	28.087	28.198	28.326	28.490
5.558	28.641	28.772	28.880	29.010	29.146	29.294	29.422	29.555	29.666	29.800
5.836	29.916	30.044	30.157	30.291	30.436	30.561	30.705	30.796	30.930	31.052
6.113	31.188	31.307	31.455	31.566	31.711	31.838	31.952	32.080	32.205	32.321
6.391	32.446	32.577	32.693	32.818	32.963	33.068	33.207	33.326	33.457	33.554
6.669	33.696	33.835	33.965	34.079	34.195	34.317	34.457	34.590	34.692	34.806
6.947	34.928	35.087	35.212	35.351	35.445	35.558	35.703	35.837	35.947	36.078
7.225	36.197	36.328	36.453	36.569	36.708	36.822	36.956	37.044	37.186	37.308
7.503	37.430	37.563	37.682	37.785	37.907	38.026	38.148	38.270	38.387	38.509
7.781	38.637	38.759	38.884	39.029	39.153	39.256	39.392	39.474	39.599	39.721
8.059	39.846	39.988	40.116	40.247	40.343	40.474	40.605	40.724	40.829	40.957
8.337	41.073	41.207	41.357	41.437	41.553	41.686	41.817	41.945	42.070	42.212
8.614	42.311	42.419	42.541	42.652	42.800	42.939	42.998	43.120	43.251	43.382
8.892	43.492	43.612	43.757	43.876	43.995	44.114	44.236	44.356	44.475	44.574
9.170	44.708	44.813	44.944	45.051	45.171	45.299	45.429	45.526	45.642	45.747
9.448	45.878	45.986	46.105	46.241	46.349	46.471	46.591	46.727	46.852	46.963
9.726	47.082	47.218	47.326	47.440	47.565	47.698	47.823	47.902	48.016	48.127
10.004	48.272	48.411	48.522	48.638	48.752	48.891	49.007	49.070	49.206	49.339
10.282	49.470	49.567	49.683	49.799	49.902	50.027	50.146	50.262	50.379	50.492
10.560	50.620	50.728	50.827	50.952	51.066	51.194	51.293	51.415	51.534	51.657
10.838	51.773	51.878	51.997	52.094	52.222	52.349	52.477	52.591	52.702	52.824
11.115	52.929	53.062	53.173	53.309	53.423	53.531	53.653	53.764	53.880	54.002
11.393	54.096	54.212	54.306	54.425	54.579	54.681	54.766	54.897	55.033	55.124
11.671	55.249	55.368	55.482	55.601	55.712	55.834	55.953	56.058	56.189	56.299
11.949	56.416	56.512	56.612	56.740	56.856	56.964	57.077	57.194	57.327	57.447
12.227	57.572	57.677	57.785	57.898	58.020	58.105	58.228	58.341	58.460	58.574
12.505	58.690	58.810	58.920	59.003	59.145	59.250	59.349	59.480	59.562	59.664
12.783	59.804	59.917	60.031	60.161	60.258	60.357	60.468	60.619	60.746	60.851
13.061	60.959	61.081	61.198	61.300	61.402	61.510	61.604	61.723	61.825	61.925
13.338	62.061	62.152	62.260	62.373	62.481	62.606	62.723	62.828	62.939	63.044
13.616	63.169	63.271	63.382	63.487	63.583	63.728	63.833	63.941	64.049	64.168
13.894	64.285	64.370	64.498	64.591	64.711	64.824	64.938	65.046	65.139	65.261
14.172	65.366	65.477	65.582	65.693	65.824	65.943	66.025	66.119	66.247	66.366
14.450	66.463	66.582	66.687	66.803	66.917	67.016	67.107	67.204	67.329	67.454
14.728	67.533	67.638	67.732	67.843	67.945	68.050	68.152	68.257	68.377	68.490
15.006	68.587	68.700	68.814	68.910	69.024	69.138	69.260	69.362	69.473	69.572
15.284	69.674	69.805	69.907	70.012	70.114	70.219	70.308	70.410	70.523	70.631
15.562	70.716	70.822	70.921	71.029	71.128	71.208	71.321	71.449	71.563	71.665
15.839	71.784	71.898	72.008	72.099	72.221	72.318	72.420	72.517	72.636	72.733
16.117	72.846	72.957	73.039	73.127	73.232	73.346	73.451	73.548	73.650	73.744
16.395	73.854	73.962	74.067	74.144	74.243	74.368	74.490	74.595	74.695	74.803
16.673	74.894	74.990	75.070	75.183	75.277	75.405	75.504	75.575	75.692	75.782
16.951	75.919	76.024	76.092	76.200	76.294	76.399	76.492	76.589	76.697	76.791

17.229	76.913	77.015	77.097	77.208	77.339	77.452	77.552	77.640	77.739	77.821
17.507	77.915	78.040	78.154	78.244	78.355	78.438	78.534	78.605	78.710	78.810
17.785	78.912	79.017	79.125	79.270	79.352	79.426	79.542	79.6[illegible]0	79.732	79.826
18.063	79.957	80.048	80.147	80.249	80.326	80.425	80.528	80.633	80.726	80.820
18.340	80.905	80.985	81.104	81.226	81.314	81.411	81.527	8[illegible].621	81.723	81.822
18.618	81.905	82.013	82.104	82.197	82.277	82.348	82.478	82.569	82.663	82.762
18.896	82.862	82.958	83.038	83.134	83.259	83.362	83.47[illegible]	83.563	83.657	83.759
19.174	83.856	83.952	84.077	84.154	84.228	84.307	84.421	84.520	84.602	84.702
19.452	84.798	84.909	84.994	85.114	85.219	85.312	85.392	85.483	85.570	85.687
19.730	85.781	85.858	85.977	86.076	86.178	86.249	86.335	86.437	86.536	86.644
20.008	86.729	86.849	86.937	87.050	87.133	87.226	87.331	87.431	87.516	87.581
20.286	87.703	87.783	87.879	87.987	88.073	88.200	88.266	88.348	88.459	88.558
20.564	88.649	88.754	88.839	88.941	89.021	89.101	89.186	89.296	89.427	89.509
20.841	89.626	89.697	89.785	89.879	89.986	90.083	90.171	90.236	90.364	90.449
21.119	90.546	90.640	90.711	90.813	90.889	90.997	91.083	91.179	91.307	91.406
21.397	91.472	91.565	91.670	91.773	91.866	91.952	92.048	92.147	92.221	92.312
21.675	92.414	92.525	92.605	92.707	92.826	92.909	92.940	93.048	93.150	93.255
21.953	93.349	93.454	93.539	93.624	93.729	93.834	93.914	94.007	94.035	94.164
22.231	94.272	94.396	94.462	94.558	94.666	94.743	94.839	94.930	95.047	95.123
22.509	95.226	95.319	95.410	95.532	95.592	95.677	95.768	95.865	95.870	96.063
22.787	96.166	96.262	96.330	96.416	96.515	96.611	96.708	96.807	96.881	96.981
23.064	97.054	97.148	97.262	97.344	97.455	97.534	97.639	97.719	97.818	97.892
23.342	97.983	98.077	98.165	98.267	98.389	98.503	98.613	98.696	98.778	98.866
23.620	98.957	99.056	99.139	99.207	99.286	99.360	99.445	99.559	99.670	99.786
23.898	99.849	99.954	100.030	100.110	100.226	100.329	100.417	100.493	100.576	100.672
24.176	100.774	100.862	100.956	101.047	101.109	101.192	101.291	101.388	101.481	101.592
24.454	101.700	101.797	101.859	101.959	102.061	102.137	102.248	102.325	102.413	102.470
24.732	102.572	102.634	102.731	102.839	102.941	103.035	103.129	103.199	103.305	103.384
25.010	103.455	103.552	103.679	103.759	103.833	103.892	103.969	104.051	104.134	104.250
25.288	104.350	104.452	104.523	104.622	104.730	104.838	104.923	105.025	105.105	105.199
25.565	105.292	105.383	105.451	105.537	105.642	105.730	105.803	105.872	105.945	106.045
25.843	106.161	106.258	106.357	106.425	106.494	106.604	106.709	106.806	106.891	106.973
26.121	107.073	107.158	107.243	107.306	107.388	107.456	107.536	107.641	107.734	107.842
26.399	107.933	108.030	108.112	108.183	108.257	108.356	108.444	108.552	108.649	108.717
26.677	108.782	108.876	108.970	109.078	109.151	109.251	109.364	109.430	109.515	109.606
26.955	109.719	109.813	109.898	109.958	110.020	110.140	110.225	110.338	110.404	110.463
27.233	110.543	110.648	110.739	110.833	110.912	110.980	111.068	111.179	111.295	111.375
27.511	111.477	111.562	111.656	111.755	111.841	111.957	112.034	112.127	112.230	112.289
27.789	112.360	112.448	112.522	112.650	112.729	112.829	112.871	112.965	113.056	113.130
28.066	113.243	113.351	113.439	113.550	113.638	113.686	113.777	113.865	113.951	114.056
28.344	114.149	114.252	114.345	114.405	114.496	114.589	114.675	114.726	114.885	114.973
28.622	115.047	115.146	115.214	115.328	115.404	115.495	115.569	115.615	115.674	115.762
28.900	115.862	115.961	116.041	116.114	116.217	116.310	116.407	116.518	116.603	116.671
29.178	116.756	116.855	116.924	117.046	117.145	117.230	117.318	117.418	117.506	117.594
29.456	117.679	117.770	117.875	117.977	118.031	118.131	118.227	118.321	118.395	118.494
29.734	118.571	118.667	118.747	118.838	118.877	118.988	119.102	119.184	119.252	119.340
30.012	119.408	119.502	119.621	119.707	119.814	119.908	119.996	120.121	120.198	120.269
30.289	120.348	120.453	120.561	120.632	120.712	120.803	120.882	120.970	121.053	121.138
30.567	121.217	121.319	121.442	121.527	121.598	121.694	121.765	121.823	121.927	122.021
30.845	122.100	122.177	122.282	122.379	122.487	122.566	122.646	122.739	122.816	122.935
31.123	123.035	123.137	123.233	123.336	123.432	123.534	123.622	123.682	123.756	123.858
31.401	123.923	124.011	124.085	124.179	124.264	124.338	124.429	124.503	124.619	124.673
31.679	124.767	124.863	124.940	125.034	125.091	125.181	125.289	125.369	125.460	125.553
31.957	125.627	125.715	125.800	125.900	125.979	126.067	126.170	126.263	126.366	126.462
32.235	126.556	126.641	126.715	126.823	126.888	126.956	127.050	127.158	127.263	127.328
32.513	127.450	127.504	127.595	127.683	127.768	127.845	127.925	127.996	128.095	128.197
32.790	128.287	128.376	128.490	128.566	128.671	128.762	128.828	128.921	129.006	129.092
33.068	129.194	129.305	129.393	129.506	129.577	129.668	129.753	129.853	129.924	130.026
33.346	130.086	130.165	130.239	130.335	130.429	130.514	130.608	130.671	130.776	130.844
33.624	130.943	131.060	131.139	131.224	131.321	131.395	131.483	131.568	131.647	131.72[illegible]
33.902	131.804	131.905	132.002	132.113	132.218	132.289	132.386	132.457	132.533	132.650
34.180	132.712	132.806	132.900	132.971	133.050	133.141	133.198	133.294	133.380	133.476
34.458	133.558	133.635	133.717	133.828	133.933	133.999	134.078	134.180	134.277	134.362
34.736	134.413	134.518	134.615	134.694	134.771	134.879	134.990	135.069	135.177	135.240
35.014	135.305	135.401	135.492	135.583	135.705	135.788	135.884	135.964	136.038	136.120
35.291	136.231	136.307	136.387	136.432	136.517	136.640	136.739	136.804	136.918	137.000
35.569	137.083	137.165	137.244	137.332	137.418	137.523	137.608	137.693	137.781	137.886
35.847	137.977	138.059	138.133	138.221	138.321	138.394	138.474	138.579	138.681	138.730
36.125	138.835	138.903	138.968	139.059	139.150	139.235	139.337	139.417	139.499	139.593
36.403	139.686	139.766	139.874	139.968	140.047	140.129	140.218	140.291	140.391	140.465
36.681	140.555	140.624	140.731	140.805	140.902	140.998	141.092	141.172	141.265	141.353

36.959	141.450	141.529	141.612	141.680	141.757	141.865	141.967	142.066	142.148	142.234
37.237	142.316	142.387	142.484	142.574	142.665	142.750	142.850	142.949	143.026	143.125
37.515	143.202	143.290	143.353	143.466	143.571	143.656	143.739	143.798	143.903	143.997
37.792	144.079	144.173	144.264	144.358	144.412	144.508	144.579	144.670	144.747	144.846
38.070	144.934	145.059	145.136	145.232	145.315	145.423	145.496	145.562	145.667	145.769
38.348	145.834	145.928	146.027	146.107	146.195	146.289	146.351	146.456	146.556	146.649
38.626	146.743	146.845	146.939	147.050	147.124	147.223	147.302	147.365	147.462	147.527
38.904	147.606									

TABLE B-3. E675 CALIBRATION DATA, (x, t), DISTANCE VS. TIME

Time increment = 16.6725 ns
Number of points = 901

μs	<-------				Units:	mm				------->
0.000	0.000	0.113	0.302	0.467	0.574	0.668	0.753	0.848	0.959	1.056
0.167	1.149	1.242	1.337	1.435	1.520	1.606	1.696	1.785	1.892	1.981
0.333	2.073	2.171	2.275	2.357	2.453	2.536	2.625	2.721	2.804	2.888
0.500	2.991	3.098	3.210	3.284	3.368	3.456	3.554	3.649	3.746	3.836
0.667	3.917	4.003	4.082	4.192	4.286	4.381	4.462	4.558	4.650	4.747
0.834	4.836	4.926	5.022	5.116	5.192	5.298	5.400	5.478	5.570	5.662
1.000	5.744	5.841	5.935	6.011	6.115	6.179	6.274	6.383	6.469	6.570
1.167	6.652	6.744	6.831	6.913	7.006	7.106	7.195	7.292	7.377	7.468
1.334	7.567	7.649	7.743	7.838	7.922	8.002	8.102	8.176	8.257	8.349
1.501	8.437	8.519	8.617	8.705	8.824	8.890	8.983	9.058	9.159	9.235
1.667	9.320	9.409	9.509	9.573	9.648	9.730	9.816	9.903	10.010	10.089
1.834	10.174	10.256	10.364	10.443	10.535	10.628	10.730	10.802	10.878	10.964
2.001	11.062	11.153	11.232	11.310	11.390	11.477	11.569	11.651	11.745	11.828
2.167	11.923	11.998	12.086	12.177	12.257	12.341	12.432	12.503	12.593	12.670
2.334	12.761	12.850	12.941	13.029	13.123	13.196	13.278	13.367	13.445	13.531
2.501	13.609	13.705	13.796	13.874	13.949	14.025	14.101	14.197	14.291	14.375
2.668	14.455	14.531	14.602	14.685	14.782	14.877	14.957	15.044	15.127	15.202
2.834	15.297	15.379	15.463	15.536	15.616	15.698	15.786	15.877	15.949	16.034
3.001	16.117	16.192	16.277	16.363	16.445	16.515	16.605	16.690	16.770	16.846
3.168	16.928	17.010	17.095	17.186	17.265	17.356	17.436	17.529	17.606	17.688
3.334	17.763	17.858	17.930	18.006	18.091	18.170	18.246	18.322	18.417	18.495
3.501	18.584	18.678	18.745	18.822	18.911	18.987	19.076	19.167	19.232	19.318
3.668	19.396	19.476	19.560	19.621	19.712	19.776	19.861	19.953	20.035	20.116
3.835	20.202	20.286	20.359	20.431	20.523	20.605	20.696	20.778	20.844	20.920
4.001	21.000	21.082	21.172	21.249	21.303	21.387	21.466	21.551	21.633	21.705
4.168	21.800	21.904	21.973	22.056	22.131	22.205	22.282	22.371	22.451	22.536
4.335	22.605	22.683	22.768	22.853	22.933	23.009	23.075	23.165	23.247	23.323
4.502	23.406	23.491	23.580	23.664	23.728	23.807	23.884	23.967	24.024	24.094
4.668	24.179	24.258	24.345	24.416	24.494	24.582	24.665	24.737	24.824	24.894
4.835	24.979	25.062	25.144	25.207	25.283	25.365	25.434	25.516	25.601	25.668
5.002	25.750	25.827	25.910	25.986	26.068	26.150	26.225	26.305	26.393	26.474
5.168	26.546	26.617	26.708	26.774	26.863	26.932	27.013	27.098	27.180	27.223
5.335	27.304	27.366	27.424	27.500	27.590	27.667	27.758	27.827	27.890	27.978
5.502	28.071	28.149	28.226	28.301	28.370	28.445	28.521	28.613	28.679	28.757
5.669	28.843	28.922	28.989	29.060	29.143	29.221	29.288	29.360	29.459	29.540
5.835	29.610	29.701	29.770	29.834	29.905	29.972	30.061	30.130	30.221	30.285
6.002	30.367	30.445	30.517	30.599	30.684	30.746	30.826	30.913	30.975	31.076
6.169	31.154	31.206	31.285	31.367	31.432	31.511	31.591	31.670	31.742	31.812
6.336	31.874	31.952	32.020	32.097	32.171	32.246	32.322	32.400	32.479	32.568
6.502	32.644	32.723	32.802	32.883	32.959	33.031	33.092	33.158	33.227	33.312
6.669	33.392	33.448	33.542	33.606	33.688	33.770	33.843	33.914	33.991	34.075
6.836	34.149	34.228	34.302	34.359	34.435	34.501	34.574	34.652	34.722	34.797
7.002	34.873	34.945	35.029	35.092	35.176	35.256	35.328	35.395	35.463	35.535
7.169	35.611	35.680	35.757	35.841	35.915	36.002	36.075	36.138	36.220	36.290
7.336	36.368	36.447	36.501	36.580	36.655	36.731	36.801	36.880	36.953	37.022
7.503	37.090	37.166	37.248	37.339	37.393	37.462	37.527	37.601	37.677	37.746
7.669	37.820	37.882	37.962	38.047	38.129	38.200	38.279	38.355	38.437	38.507
7.836	38.585	38.651	38.719	38.796	38.882	38.949	39.017	39.078	39.156	39.249
8.003	39.318	39.391	39.463	39.525	39.596	39.670	39.749	39.815	39.892	39.973
8.170	40.049	40.124	40.168	40.248	40.307	40.387	40.452	40.535	40.607	40.671
8.336	40.740	40.829	40.904	40.973	41.056	41.127	41.188	41.264	41.337	41.419
8.503	41.503	41.561	41.635	41.704	41.765	41.841	41.917	41.985	42.067	42.131
8.670	42.179	42.267	42.345	42.418	42.487	42.548	42.632	42.702	42.772	42.841
8.836	42.904	42.996	43.070	43.137	43.199	43.264	43.327	43.398	43.471	43.541
9.003	43.630	43.702	43.777	43.846	43.923	43.982	44.073	44.147	44.212	44.295
9.170	44.368	44.439	44.502	44.563	44.647	44.708	44.789	44.841	44.912	44.982
9.337	45.065	45.153	45.224	45.294	45.366	45.437	45.505	45.568	45.645	45.707
9.503	45.786	45.852	45.947	46.016	46.085	46.146	46.203	46.260	46.329	46.408
9.670	46.481	46.552	46.616	46.695	46.751	46.840	46.919	46.978	47.047	47.121
9.837	47.194	47.271	47.342	47.429	47.498	47.563	47.625	47.689	47.758	47.845
10.004	47.911	47.982	48.053	48.124	48.193	48.265	48.335	48.404	48.467	48.549
10.170	48.632	48.707	48.757	48.824	48.914	48.969	49.037	49.102	49.168	49.246

10.337	49.324	49.375	49.454	49.529	49.594	49.673	49.744	49.802	49.870	49.947
10.504	49.999	50.076	50.167	50.237	50.306	50.363	50.436	50.501	50.574	50.646
10.670	50.720	50.783	50.843	50.912	50.990	51.059	51.123	51.196	51.264	51.334
10.837	51.407	51.469	51.552	51.630	51.701	51.770	51.830	51.911	51.986	52.065
11.004	52.123	52.179	52.253	52.328	52.388	52.475	52.532	52.592	52.661	52.725
11.171	52.797	52.882	52.949	53.024	53.088	53.163	53.226	53.283	53.350	53.428
11.337	53.513	53.573	53.642	53.710	53.778	53.852	53.929	53.993	54.062	54.135
11.504	54.207	54.267	54.336	54.412	54.479	54.548	54.609	54.681	54.749	54.819
11.671	54.885	54.957	55.031	55.088	55.157	55.224	55.287	55.374	55.446	55.506
11.837	55.588	55.652	55.725	55.796	55.870	55.930	55.999	56.066	56.144	56.204
12.004	56.270	56.339	56.411	56.485	56.553	56.614	56.681	56.740	56.810	56.891
12.171	56.948	57.014	57.081	57.163	57.214	57.289	57.364	57.437	57.526	57.592
12.338	57.661	57.716	57.787	57.838	57.891	57.958	58.042	58.111	58.179	58.254
12.504	58.336	58.396	58.468	58.542	58.594	58.668	58.734	58.790	58.854	58.914
12.671	58.985	59.061	59.127	59.204	59.272	59.330	59.395	59.468	59.529	59.591
12.838	59.654	59.730	59.784	59.863	59.939	60.013	60.081	60.143	60.203	60.288
13.005	60.346	60.405	60.481	60.559	60.632	60.696	60.768	60.821	60.879	60.947
13.171	61.016	61.087	61.165	61.238	61.300	61.374	61.429	61.500	61.573	61.645
13.338	61.689	61.758	61.830	61.890	61.964	62.030	62.095	62.165	62.213	62.276
13.505	62.341	62.415	62.475	62.546	62.626	62.689	62.754	62.820	62.884	62.960
13.671	63.019	63.068	63.133	63.205	63.281	63.345	63.386	63.455	63.528	63.591
13.838	63.663	63.738	63.796	63.849	63.913	63.995	64.055	64.123	64.184	64.240
14.005	64.309	64.369	64.448	64.520	64.590	64.650	64.701	64.776	64.858	64.921
14.172	64.985	65.047	65.118	65.181	65.246	65.297	65.357	65.423	65.483	65.549
14.338	65.618	65.687	65.761	65.823	65.887	65.919	65.969	66.016	66.069	66.141
14.505	66.198	66.262	66.340	66.408	66.477	66.531	66.596	66.638	66.693	66.764
14.672	66.835	66.898	66.950	67.019	67.072	67.141	67.208	67.264	67.338	67.410
14.839	67.482	67.540	67.606	67.668	67.719	67.778	67.851	67.928	67.997	68.053
15.005	68.116									

TABLE B-4. E673 CALIBRATION, (U_S, t), SHOCK VELOCITY VS. TIME, OBTAINED BY APPLYING NERD FILTER TO DATA OF TABLE B-1

Time increment = 27.7515 ns
Number of points = 505

μs	Units: km/s									
0.000	–	–	–	–	–	–	–	–	–	–
0.278	–	–	–	–	–	–	–	–	–	–
0.555	–	–	–	–	–	–	–	–	–	–
0.833	–	–	–	–	–	–	–	–	–	–
1.110	–	–	–	–	–	5.487	5.480	5.473	5.465	5.458
1.388	5.450	5.442	5.434	5.426	5.418	5.409	5.402	5.394	5.386	5.378
1.665	5.370	5.362	5.354	5.346	5.338	5.330	5.322	5.314	5.306	5.299
1.943	5.291	5.283	5.276	5.268	5.261	5.254	5.247	5.239	5.232	5.225
2.220	5.218	5.210	5.203	5.196	5.189	5.182	5.175	5.168	5.161	5.154
2.498	5.148	5.141	5.134	5.128	5.121	5.114	5.108	5.101	5.095	5.088
2.775	5.082	5.076	5.069	5.063	5.057	5.051	5.044	5.038	5.032	5.026
3.053	5.020	5.014	5.009	5.003	4.997	4.991	4.985	4.980	4.974	4.968
3.330	4.963	4.957	4.952	4.947	4.941	4.936	4.930	4.925	4.920	4.914
3.608	4.909	4.904	4.899	4.894	4.889	4.884	4.880	4.875	4.870	4.865
3.885	4.861	4.856	4.852	4.847	4.843	4.839	4.835	4.831	4.827	4.823
4.163	4.819	4.815	4.812	4.808	4.804	4.801	4.797	4.794	4.791	4.787
4.440	4.784	4.781	4.778	4.775	4.772	4.770	4.767	4.764	4.761	4.758
4.718	4.755	4.752	4.749	4.747	4.744	4.741	4.738	4.735	4.732	4.728
4.995	4.725	4.722	4.719	4.715	4.712	4.708	4.704	4.701	4.697	4.693
5.273	4.689	4.685	4.681	4.677	4.673	4.668	4.664	4.660	4.655	4.651
5.550	4.647	4.642	4.638	4.634	4.630	4.625	4.621	4.617	4.613	4.609
5.828	4.605	4.602	4.598	4.594	4.591	4.587	4.584	4.580	4.577	4.574
6.105	4.571	4.568	4.565	4.562	4.559	4.556	4.554	4.551	4.548	4.546
6.383	4.543	4.540	4.538	4.536	4.533	4.531	4.528	4.526	4.523	4.520
6.660	4.518	4.515	4.512	4.510	4.507	4.504	4.501	4.499	4.496	4.493
6.938	4.490	4.487	4.484	4.481	4.478	4.476	4.473	4.470	4.467	4.464
7.215	4.462	4.459	4.456	4.454	4.451	4.449	4.446	4.444	4.442	4.439
7.493	4.437	4.435	4.433	4.431	4.429	4.427	4.425	4.424	4.422	4.420
7.770	4.419	4.417	4.416	4.414	4.412	4.411	4.409	4.408	4.406	4.404
8.048	4.403	4.401	4.399	4.397	4.396	4.394	4.392	4.390	4.388	4.386
8.325	4.384	4.382	4.380	4.378	4.376	4.374	4.372	4.369	4.367	4.365
8.603	4.363	4.361	4.359	4.357	4.354	4.352	4.350	4.349	4.347	4.345
8.880	4.343	4.341	4.339	4.337	4.336	4.334	4.332	4.331	4.329	4.327
9.158	4.326	4.324	4.323	4.321	4.320	4.319	4.317	4.316	4.315	4.313
9.436	4.312	4.310	4.309	4.307	4.305	4.304	4.302	4.300	4.299	4.297
9.713	4.295	4.292	4.290	4.288	4.286	4.283	4.281	4.278	4.275	4.273
9.991	4.270	4.267	4.265	4.262	4.259	4.256	4.253	4.251	4.248	4.245
10.268	4.243	4.240	4.238	4.235	4.233	4.231	4.229	4.226	4.224	4.222
10.546	4.221	4.219	4.217	4.216	4.215	4.213	4.212	4.211	4.210	4.210
10.823	4.209	4.208	4.207	4.207	4.206	4.205	4.205	4.204	4.203	4.202
11.101	4.202	4.201	4.200	4.199	4.198	4.197	4.196	4.195	4.194	4.192
11.378	4.191	4.189	4.188	4.186	4.184	4.182	4.179	4.177	4.175	4.172
11.656	4.170	4.167	4.165	4.162	4.159	4.157	4.154	4.152	4.149	4.146
11.933	4.144	4.141	4.139	4.136	4.134	4.131	4.129	4.127	4.125	4.123
12.211	4.121	4.119	4.117	4.116	4.114	4.112	4.111	4.109	4.107	4.106
12.488	4.105	4.103	4.102	4.100	4.099	4.097	4.096	4.094	4.093	4.091
12.766	4.090	4.088	4.086	4.084	4.082	4.080	4.078	4.076	4.073	4.071
13.043	4.068	4.065	4.063	4.060	4.057	4.054	4.051	4.048	4.044	4.041
13.321	4.037	4.034	4.030	4.027	4.023	4.019	4.015	4.012	4.008	4.004
13.598	4.000	3.996	3.993	3.989	3.985	3.981	3.977	3.973	3.969	3.965
13.876	3.961	3.957	3.952	3.947	3.942					

TABLE B-5. E674 CALIBRATION, (U_S, t), SHOCK VELOCITY VS. TIME, OBTAINED BY APPLYING NERD FILTER TO DATA OF TABLE B-2

Time increment = 27.7885 ns
Number of points = 1357

µs	Units: km/s									
0.000	-	-	-	-	-	-	-	-	-	-
0.278	-	-	-	-	-	-	-	-	-	-
0.556	-	-	-	-	-	-	-	-	-	-
0.834	-	-	-	-	-	-	-	-	-	-
1.112	-	-	-	-	-	5.470	5.459	5.447	5.436	5.425
1.389	5.414	5.404	5.394	5.384	5.375	5.365	5.355	5.346	5.336	5.327
1.667	5.318	5.308	5.299	5.290	5.281	5.273	5.264	5.255	5.247	5.239
1.945	5.230	5.222	5.215	5.207	5.199	5.192	5.185	5.178	5.171	5.164
2.223	5.158	5.151	5.145	5.139	5.133	5.127	5.121	5.116	5.110	5.105
2.501	5.099	5.094	5.089	5.084	5.079	5.074	5.069	5.064	5.059	5.054
2.779	5.049	5.044	5.039	5.034	5.029	5.024	5.018	5.013	5.008	5.003
3.057	4.998	4.992	4.987	4.981	4.975	4.970	4.964	4.959	4.953	4.947
3.335	4.941	4.935	4.930	4.924	4.919	4.913	4.907	4.902	4.897	4.891
3.613	4.886	4.881	4.876	4.871	4.866	4.861	4.856	4.851	4.847	4.842
3.890	4.837	4.833	4.829	4.825	4.821	4.817	4.813	4.809	4.805	4.801
4.168	4.798	4.794	4.791	4.787	4.784	4.780	4.777	4.773	4.770	4.766
4.446	4.763	4.760	4.756	4.753	4.749	4.746	4.743	4.740	4.736	4.733
4.724	4.730	4.726	4.723	4.720	4.717	4.714	4.710	4.707	4.704	4.701
5.002	4.698	4.695	4.692	4.689	4.686	4.683	4.680	4.677	4.674	4.671
5.280	4.668	4.665	4.662	4.659	4.657	4.654	4.651	4.648	4.645	4.642
5.558	4.639	4.635	4.632	4.629	4.626	4.623	4.619	4.616	4.612	4.609
5.836	4.606	4.602	4.598	4.595	4.592	4.588	4.584	4.581	4.577	4.574
6.113	4.570	4.566	4.563	4.559	4.556	4.552	4.549	4.546	4.542	4.539
6.391	4.536	4.533	4.530	4.526	4.523	4.520	4.517	4.514	4.511	4.509
6.669	4.506	4.503	4.500	4.497	4.494	4.491	4.489	4.486	4.483	4.480
6.947	4.477	4.475	4.472	4.469	4.466	4.463	4.460	4.457	4.454	4.451
7.225	4.448	4.445	4.443	4.440	4.437	4.434	4.432	4.429	4.426	4.424
7.503	4.421	4.419	4.417	4.414	4.412	4.410	4.408	4.406	4.404	4.402
7.781	4.401	4.399	4.397	4.396	4.394	4.393	4.392	4.390	4.389	4.388
8.059	4.386	4.385	4.384	4.382	4.381	4.379	4.378	4.376	4.375	4.373
8.337	4.371	4.369	4.367	4.365	4.363	4.361	4.359	4.357	4.355	4.352
8.614	4.350	4.348	4.345	4.343	4.340	4.338	4.335	4.333	4.330	4.328
8.892	4.325	4.323	4.321	4.318	4.316	4.314	4.312	4.310	4.308	4.306
9.170	4.304	4.303	4.301	4.299	4.298	4.296	4.294	4.293	4.292	4.290
9.448	4.289	4.287	4.286	4.284	4.282	4.281	4.279	4.277	4.275	4.273
9.726	4.271	4.269	4.267	4.265	4.263	4.261	4.258	4.256	4.253	4.251
10.004	4.248	4.246	4.243	4.240	4.238	4.235	4.232	4.230	4.227	4.225
10.282	4.222	4.220	4.217	4.215	4.213	4.211	4.209	4.206	4.205	4.203
10.560	4.201	4.199	4.198	4.196	4.195	4.193	4.192	4.191	4.190	4.188
10.838	4.187	4.186	4.185	4.184	4.183	4.182	4.181	4.181	4.180	4.179
11.115	4.178	4.177	4.176	4.174	4.173	4.172	4.171	4.169	4.168	4.167
11.393	4.165	4.164	4.162	4.160	4.159	4.157	4.155	4.153	4.151	4.149
11.671	4.147	4.145	4.143	4.140	4.138	4.136	4.134	4.132	4.130	4.128
11.949	4.126	4.124	4.122	4.119	4.117	4.115	4.113	4.111	4.108	4.106
12.227	4.104	4.102	4.099	4.097	4.095	4.093	4.090	4.088	4.086	4.084
12.505	4.081	4.079	4.076	4.074	4.072	4.069	4.067	4.064	4.062	4.059
12.783	4.057	4.054	4.051	4.049	4.046	4.044	4.041	4.039	4.036	4.034
13.061	4.032	4.029	4.027	4.024	4.022	4.020	4.017	4.015	4.013	4.011
13.338	4.008	4.006	4.004	4.002	4.000	3.998	3.996	3.994	3.992	3.989
13.616	3.987	3.985	3.983	3.980	3.978	3.976	3.973	3.971	3.968	3.965
13.894	3.963	3.960	3.957	3.954	3.951	3.948	3.945	3.943	3.940	3.937
14.172	3.934	3.930	3.927	3.924	3.921	3.918	3.915	3.911	3.908	3.905
14.450	3.901	3.898	3.894	3.891	3.888	3.884	3.881	3.878	3.875	3.872
14.728	3.869	3.866	3.863	3.860	3.858	3.855	3.853	3.850	3.848	3.845
15.006	3.843	3.841	3.838	3.836	3.834	3.832	3.830	3.827	3.825	3.823
15.284	3.821	3.818	3.816	3.814	3.812	3.810	3.807	3.805	3.803	3.800
15.562	3.798	3.795	3.793	3.790	3.788	3.785	3.782	3.780	3.777	3.774
15.839	3.771	3.768	3.765	3.762	3.759	3.755	3.752	3.749	3.746	3.742
16.117	3.739	3.736	3.733	3.729	3.726	3.723	3.720	3.717	3.714	3.711
16.395	3.708	3.705	3.703	3.700	3.697	3.694	3.692	3.689	3.887	3.684
16.673	3.682	3.680	3.678	3.675	3.673	3.671	3.669	3.667	3.666	3.664

16.951	3.662	3.660	3.659	3.657	3.656	3.654	3.653	3.651	3.650	3.648
17.229	3.646	3.645	3.643	3.642	3.640	3.638	3.636	3.635	3.633	3.631
17.507	3.629	3.626	3.624	3.622	3.619	3.617	3.614	3.612	3.609	3.606
17.785	3.603	3.601	3.598	3.595	3.592	3.589	3.586	3.583	3.580	3.577
18.063	3.574	3.571	3.568	3.565	3.562	3.559	3.556	3.553	3.550	3.548
18.340	3.545	3.542	3.540	3.537	3.534	3.532	3.530	3.527	3.525	3.523
18.618	3.521	3.519	3.517	3.516	3.514	3.512	3.510	3.509	3.507	3.506
18.896	3.504	3.503	3.502	3.500	3.499	3.498	3.496	3.495	3.494	3.493
19.174	3.492	3.491	3.490	3.489	3.488	3.487	3.486	3.484	3.483	3.482
19.452	3.481	3.480	3.478	3.477	3.476	3.475	3.473	3.472	3.470	3.469
19.730	3.468	3.466	3.465	3.463	3.462	3.461	3.459	3.458	3.456	3.454
20.008	3.453	3.451	3.449	3.447	3.446	3.444	3.442	3.440	3.439	3.437
20.286	3.435	3.434	3.432	3.430	3.429	3.427	3.425	3.424	3.422	3.420
20.564	3.419	3.417	3.416	3.414	3.412	3.411	3.409	3.408	3.406	3.405
20.841	3.404	3.402	3.401	3.400	3.393	3.397	3.396	3.394	3.393	3.392
21.119	3.391	3.390	3.388	3.387	3.386	3.385	3.384	3.383	3.382	3.381
21.397	3.380	3.379	3.378	3.377	3.377	3.376	3.375	3.374	3.373	3.372
21.675	3.372	3.371	3.370	3.370	3.369	3.368	3.367	3.367	3.366	3.365
21.953	3.365	3.364	3.363	3.363	3.362	3.361	3.361	3.360	3.359	3.358
22.231	3.358	3.357	3.357	3.356	3.355	3.355	3.354	3.354	3.353	3.353
22.509	3.352	3.351	3.351	3.350	3.350	3.349	3.349	3.348	3.348	3.347
22.787	3.347	3.347	3.346	3.346	3.345	3.345	3.344	3.344	3.343	3.343
23.064	3.342	3.341	3.340	3.339	3.339	3.338	3.337	3.336	3.335	3.334
23.342	3.333	3.332	3.331	3.330	3.329	3.327	3.326	3.324	3.322	3.321
23.620	3.319	3.318	3.316	3.314	3.312	3.310	3.308	3.306	3.305	3.303
23.898	3.301	3.298	3.296	3.294	3.291	3.289	3.287	3.285	3.282	3.280
24.176	3.277	3.275	3.273	3.270	3.268	3.266	3.264	3.262	3.260	3.258
24.454	3.256	3.254	3.252	3.250	3.248	3.247	3.245	3.243	3.242	3.241
24.732	3.239	3.238	3.237	3.237	3.236	3.235	3.234	3.234	3.233	3.232
25.010	3.231	3.231	3.230	3.229	3.229	3.229	3.228	3.228	3.227	3.227
25.288	3.226	3.226	3.225	3.224	3.224	3.223	3.222	3.221	3.220	3.219
25.565	3.218	3.216	3.215	3.214	3.212	3.211	3.210	3.208	3.207	3.205
25.843	3.204	3.202	3.201	3.199	3.198	3.196	3.194	3.193	3.19[illegible]	3.190
26.121	3.188	3.187	3.186	3.184	3.183	3.182	3.181	3.180	3.18[illegible]	3.179
26.399	3.179	3.178	3.178	3.178	3.178	3.176	3.178	3.178	3.179	3.179
26.677	3.180	3.181	3.181	3.182	3.183	3.184	3.184	3.185	3.186	3.187
26.955	3.189	3.190	3.191	3.192	3.192	3.193	3.194	3.196	3.197	3.198
27.233	3.199	3.200	3.201	3.201	3.202	3.203	3.204	3.205	3.206	3.206
27.511	3.207	3.207	3.208	3.208	3.208	3.208	3.208	3.208	3.208	3.207
27.789	3.206	3.206	3.205	3.204	3.203	3.202	3.201	3.200	3.198	3.197
28.066	3.195	3.194	3.192	3.190	3.189	3.187	3.186	3.184	3.183	3.181
28.344	3.179	3.178	3.177	3.176	3.174	3.173	3.172	3.172	3.171	3.171
28.622	3.170	3.170	3.170	3.170	3.171	3.171	3.171	3.172	3.173	3.173
28.900	3.174	3.176	3.177	3.178	3.179	3.181	3.182	3.183	3.185	3.186
29.178	3.188	3.190	3.191	3.192	3.194	3.195	3.196	3.198	3.199	3.201
29.456	3.202	3.203	3.204	3.205	3.205	3.206	3.207	3.207	3.208	3.208
29.734	3.208	3.208	3.208	3.208	3.208	3.208	3.208	3.207	3.207	3.207
30.012	3.207	3.207	3.207	3.207	3.207	3.207	3.207	3.207	3.207	3.207
30.289	3.207	3.208	3.208	3.208	3.209	3.209	3.209	3.209	3.209	3.210
30.567	3.210	3.210	3.210	3.210	3.209	3.209	3.209	3.208	3.207	3.206
30.845	3.205	3.204	3.202	3.201	3.199	3.198	3.196	3.194	3.192	3.190
31.123	3.188	3.186	3.183	3.181	3.179	3.177	3.175	3.172	3.170	3.168
31.401	3.166	3.165	3.163	3.161	3.160	3.158	3.157	3.156	3.155	3.154
31.679	3.153	3.153	3.152	3.152	3.152	3.152	3.152	3.153	3.154	3.155
31.957	3.156	3.157	3.159	3.160	3.162	3.163	3.165	3.167	3.169	3.171
32.235	3.173	3.175	3.176	3.178	3.180	3.182	3.183	3.185	3.187	3.188
32.513	3.190	3.191	3.192	3.193	3.194	3.194	3.194	3.194	3.194	3.194
32.790	3.194	3.194	3.194	3.193	3.193	3.192	3.191	3.190	3.190	3.189
33.068	3.188	3.186	3.185	3.184	3.183	3.181	3.180	3.178	3.176	3.175
33.346	3.173	3.172	3.170	3.168	3.167	3.165	3.163	3.162	3.160	3.158
33.624	3.156	3.155	3.153	3.151	3.150	3.148	3.147	3.146	3.144	3.143
33 902	3.142	3.141	3.140	3.139	3.138	3.138	3.137	3.137	3.137	3.137
34.180	3.137	3.137	3.137	3.137	3.137	3.138	3.138	3.139	3.140	3.141
34.458	3.141	3.142	3.143	3.144	3.145	3.146	3.147	3.147	3.148	3.149
34.736	3.150	3.151	3.152	3.153	3.154	3.155	3.155	3.156	3.157	3.157
35.014	3.158	3.158	3.158	3.158	3.158	3.158	3.158	3.157	3.157	3.157
35.291	3.156	3.156	3.155	3.154	3.153	3.152	3.151	3.150	3.149	3.148
35.569	3.146	3.145	3.144	3.143	3.141	3.140	3.139	3.138	3.137	3.136
35.847	3.135	3.134	3.133	3.132	3.132	3.131	3.131	3.130	3.130	3.130
36 125	3.129	3.129	3.129	3.130	3.130	3.130	3.131	3.131	3.132	3.132
36.403	3.133	3.134	3.135	3.136	3.137	3.138	3.139	3.140	3.142	3.143

36.681	3.144	3.145	3.147	3.148	3.149	3.150	3.151	3.152	3.154	3.155
36.959	3.156	3.157	3.158	3.159	3.160	3.161	3.162	3.162	3.163	3.164
37.237	3.164	3.165	3.165	3.166	3.166	3.166	3.167	3.167	3.168	3.168
37.515	3.169	3.169	3.170	3.171	3.171	3.172	3.173			

TABLE B-6. E675 CALIBRATION, (U_S, t), SHOCK VELOCITY VS. TIME, OBTAINED BY APPLYING NERD FILTER TO DATA OF TABLE B-3

Time increment = 16.6725 ns
Number of points = 857

µs	<————				Units: km/s				————>
0.000	-	-	-	-	-	-	-	-	-	-
0.167	-	-	-	-	-	-	-	-	-	-
0.333	-	-	-	-	-	-	-	-	-	-
0.500	-	-	-	-	-	-	-	-	-	-
0.667	-	-	-	-	-	5.498	5.493	5.489	5.485	5.482
0.834	5.479	5.476	5.473	5.470	5.467	5.464	5.461	5.458	5.455	5.452
1.000	5.448	5.444	5.441	5.437	5.433	5.429	5.425	5.420	5.416	5.411
1.167	5.407	5.402	5.397	5.393	5.388	5.382	5.377	5.372	5.367	5.362
1.334	5.356	5.351	5.345	5.339	5.334	5.328	5.323	5.317	5.311	5.306
1.501	5.301	5.295	5.290	5.285	5.279	5.274	5.269	5.264	5.259	5.255
1.667	5.250	5.246	5.241	5.237	5.233	5.229	5.225	5.221	5.217	5.214
1.834	5.210	5.206	5.202	5.199	5.196	5.192	5.189	5.186	5.182	5.179
2.001	5.175	5.172	5.168	5.165	5.162	5.158	5.155	5.151	5.147	5.144
2.167	5.140	5.136	5.133	5.129	5.125	5.121	5.117	5.113	5.109	5.105
2.334	5.101	5.097	5.093	5.089	5.085	5.081	5.076	5.072	5.068	5.064
2.501	5.060	5.056	5.052	5.048	5.044	5.040	5.036	5.033	5.029	5.026
2.668	5.022	5.019	5.016	5.012	5.009	5.006	5.002	4.999	4.996	4.993
2.834	4.990	4.987	4.985	4.982	4.979	4.977	4.974	4.972	4.969	4.967
3.001	4.964	4.962	4.960	4.957	4.955	4.952	4.950	4.948	4.946	4.943
3.168	4.941	4.939	4.936	4.934	4.932	4.929	4.927	4.924	4.922	4.919
3.334	4.917	4.914	4.911	4.908	4.906	4.903	4.900	4.897	4.894	4.891
3.501	4.888	4.885	4.883	4.880	4.877	4.874	4.871	4.869	4.866	4.863
3.668	4.861	4.858	4.855	4.853	4.851	4.848	4.846	4.844	4.842	4.840
3.835	4.838	4.836	4.834	4.833	4.831	4.829	4.828	4.826	4.824	4.823
4.001	4.821	4.820	4.819	4.817	4.816	4.814	4.812	4.811	4.809	4.807
4.168	4.806	4.804	4.802	4.799	4.797	4.795	4.793	4.790	4.788	4.785
4.335	4.783	4.780	4.777	4.774	4.771	4.769	4.766	4.763	4.760	4.757
4.502	4.754	4.751	4.748	4.745	4.742	4.739	4.737	4.734	4.731	4.728
4.668	4.725	4.722	4.719	4.717	4.714	4.711	4.708	4.705	4.702	4.700
4.835	4.697	4.694	4.691	4.688	4.685	4.682	4.680	4.677	4.674	4.671
5.002	4.668	4.665	4.662	4.659	4.657	4.654	4.651	4.648	4.645	4.643
5.168	4.640	4.637	4.635	4.632	4.630	4.627	4.625	4.623	4.621	4.619
5.335	4.617	4.616	4.614	4.612	4.611	4.610	4.608	4.607	4.606	4.606
5.502	4.605	4.604	4.604	4.603	4.603	4.603	4.602	4.602	4.601	4.601
5.669	4.600	4.600	4.599	4.598	[illegible]	4.597	4.596	4.595	4.594	4.593
5.835	4.591	4.590	4.589	4.587	4.586	4.584	4.582	4.580	4.578	4.576
6.002	4.574	4.572	4.570	4.568	4.565	4.563	4.561	4.558	4.556	4.553
6.169	4.551	4.549	4.546	4.544	4.542	4.540	4.538	4.535	4.533	4.531
6.336	4.529	4.527	4.525	4.523	4.521	4.519	4.517	4.515	4.513	4.511
6.502	4.509	4.507	4.505	4.503	4.501	4.499	4.497	4.496	4.494	4.492
6.669	4.489	4.487	4.485	4.483	4.482	4.480	4.478	4.476	4.474	4.472
6.836	4.471	4.469	4.467	4.465	4.464	4.462	4.460	4.459	4.457	4.455
7.002	4.454	4.452	4.450	4.449	4.448	4.446	4.445	4.444	4.442	4.441
7.169	4.440	4.439	4.438	4.437	4.436	4.436	4.435	4.434	4.434	4.433
7.336	4.433	4.432	4.431	4.431	4.430	4.430	4.429	4.429	4.428	4.428
7.503	4.427	4.427	4.426	4.425	4.425	4.424	4.423	4.423	4.422	4.421
7.669	4.420	4.419	4.417	4.416	4.415	4.413	4.412	4.411	4.409	4.408
7.836	4.406	4.404	4.402	4.401	4.399	4.397	4.394	4.392	4.390	4.388
8.003	4.386	4.383	4.381	4.379	4.376	4.374	4.372	4.369	4.367	4.365
8.170	4.362	4.360	4.358	4.355	4.353	4.351	4.348	4.346	4.344	4.342
8.336	4.340	4.338	4.336	4.334	4.332	4.330	4.328	4.327	4.325	4.324
8.503	4.322	4.321	4.320	4.319	4.317	4.316	4.315	4.314	4.313	4.312
8.670	4.312	4.311	4.310	4.309	4.309	4.308	4.308	4.308	4.307	4.307
8.836	4.307	4.307	4.307	4.307	4.307	4.306	4.306	4.306	4.306	4.306
9.003	4.305	4.305	4.304	4.304	4.303	4.302	4.302	4.301	4.300	4.299
9.170	4.298	4.298	4.296	4.295	4.294	4.292	4.291	4.289	4.288	4.286
9.337	4.284	4.283	4.281	4.279	4.278	4.276	4.274	4.273	4.271	4.270
9.503	4.268	4.267	4.265	4.264	4.263	4.262	4.261	4.260	4.259	4.258
9.670	4.257	4.256	4.255	4.254	4.254	4.253	4.252	4.252	4.251	4.250
9.837	4.250	4.249	4.248	4.248	4.247	4.246	4.245	4.244	4.243	4.242
10.004	4.241	4.239	4.238	4.236	4.235	4.233	4.231	4.229	4.228	4.226

10.170	4.224	4.223	4.221	4.219	4.217	4.215	4.214	4.212	4.210	4.209
10.337	4.207	4.206	4.204	4.203	4.202	4.200	4.199	4.198	4.197	4.196
10.504	4.195	4.195	4.194	4.194	4.193	4.193	4.192	4.192	4.192	4.191
10.670	4.191	4.191	4.191	4.191	4.190	4.190	4.190	4.190	4.189	4.189
10.837	4.189	4.189	4.188	4.188	4.187	4.187	4.186	4.186	4.185	4.185
11.004	4.184	4.183	4.182	4.181	4.181	4.180	4.179	4.178	4.177	4.176
11.171	4.175	4.174	4.173	4.172	4.171	4.170	4.169	4.168	4.168	4.167
11.337	4.166	4.165	4.164	4.163	4.162	4.162	4.161	4.160	4.159	4.158
11.504	4.157	4.156	4.155	4.154	4.153	4.152	4.152	4.151	4.150	4.149
11.671	4.148	4.147	4.146	4.145	4.144	4.143	4.142	4.141	4.139	4.138
11.837	4.137	4.136	4.135	4.133	4.132	4.130	4.129	4.128	4.126	4.125
12.004	4.123	4.122	4.120	4.119	4.117	4.115	4.113	4.112	4.110	4.108
12.171	4.106	4.104	4.103	4.101	4.099	4.097	4.095	4.093	4.091	4.089
12.338	4.088	4.086	4.084	4.082	4.080	4.079	4.077	4.075	4.074	4.072
12.504	4.071	4.070	4.068	4.067	4.066	4.065	4.064	4.063	4.062	4.062
12.671	4.061	4.060	4.060	4.059	4.059	4.058	4.057	4.057	4.056	4.055
12.838	4.055	4.054	4.053	4.052	4.052	4.051	4.050	4.049	4.047	4.046
13.005	4.045	4.043	4.042	4.040	4.038	4.036	4.034	4.032	4.030	4.027
13.171	4.024	4.021	4.018	4.016	4.012	4.009	4.006	4.003	4.000	3.996
13.338	3.993	3.990	3.986	3.983	3.979	3.976	3.973	3.970	3.967	3.964
13.505	3.961	3.959	3.956	3.954	3.951	3.949	3.947	3.945	3.943	3.941
13.671	3.939	3.938	3.936	3.934	3.932	3.931	3.929	3.927	3.925	3.923
13.838	3.921	3.918	3.916	3.913	3.910	3.907	3.904	3.901	3.897	3.893
14.005	3.889	3.885	3.880	3.876	3.871	3.866	3.861	3.855	3.850	3.844
14.172	3.839	3.633	3.828	3.822	3.817	3.811	3.806			

TABLE B-7. E673 CALIBRATION, (u_p, t), PARTICLE VELOCITY VS. TIME, OBTAINED BY APPLYING EQUATION (3-7) TO DATA OF TABLE B-4

Time increment = 27.7515 ns
Number of points = 505

μs	<—— Units: km/s ——>									
0.000	-	-	-	-	-	-	-	-	-	-
0.278	-	-	-	-	-	-	-	-	-	-
0.555	-	-	-	-	-	-	-	-	-	-
0.833	-	-	-	-	-	-	-	-	-	-
1.110	-	-	-	-	-	1.749	1.746	1.741	1.737	1.733
1.388	1.729	1.724	1.720	1.716	1.711	1.707	1.702	1.698	1.694	1.689
1.665	1.685	1.681	1.676	1.672	1.668	1.663	1.659	1.655	1.650	1.646
1.943	1.642	1.638	1.634	1.630	1.626	1.622	1.618	1.614	1.610	1.606
2.220	1.602	1.598	1.594	1.591	1.587	1.583	1.579	1.575	1.572	1.568
2.498	1.564	1.561	1.557	1.553	1.550	1.546	1.543	1.539	1.536	1.532
2.775	1.529	1.526	1.522	1.519	1.515	1.512	1.509	1.506	1.502	1.499
3.053	1.496	1.493	1.490	1.486	1.483	1.480	1.477	1.474	1.471	1.468
3.330	1.465	1.462	1.459	1.456	1.454	1.451	1.448	1.445	1.442	1.439
3.608	1.437	1.434	1.431	1.429	1.426	1.423	1.421	1.418	1.416	1.413
3.885	1.411	1.408	1.406	1.404	1.401	1.399	1.397	1.395	1.393	1.391
4.163	1.389	1.387	1.385	1.383	1.381	1.379	1.377	1.375	1.374	1.372
4.440	1.370	1.369	1.367	1.366	1.364	1.363	1.361	1.360	1.358	1.356
4.718	1.355	1.353	1.352	1.350	1.349	1.347	1.346	1.344	1.343	1.341
4.995	1.339	1.337	1.336	1.334	1.332	1.330	1.328	1.326	1.324	1.322
5.273	1.320	1.318	1.316	1.314	1.311	1.309	1.307	1.305	1.302	1.300
5.550	1.298	1.295	1.293	1.291	1.289	1.286	1.284	1.282	1.280	1.278
5.828	1.276	1.274	1.272	1.270	1.268	1.266	1.265	1.263	1.261	1.260
6.105	1.258	1.256	1.255	1.253	1.252	1.250	1.249	1.247	1.246	1.245
6.383	1.243	1.242	1.241	1.239	1.238	1.237	1.235	1.234	1.233	1.231
6.660	1.230	1.228	1.227	1.226	1.224	1.223	1.221	1.220	1.218	1.217
6.938	1.215	1.214	1.212	1.211	1.209	1.208	1.206	1.205	1.203	1.202
7.215	1.200	1.199	1.198	1.196	1.195	1.194	1.192	1.191	1.190	1.189
7.493	1.188	1.187	1.185	1.184	1.183	1.182	1.181	1.181	1.180	1.179
7.770	1.178	1.177	1.176	1.175	1.175	1.174	1.173	1.172	1.171	1.170
8.048	1.169	1.169	1.168	1.167	1.166	1.165	1.164	1.163	1.162	1.161
8.325	1.160	1.159	1.157	1.156	1.155	1.154	1.153	1.152	1.151	1.150
8.603	1.149	1.148	1.146	1.145	1.144	1.143	1.142	1.141	1.140	1.139
8.880	1.138	1.137	1.136	1.135	1.134	1.133	1.132	1.132	1.131	1.130
9.158	1.129	1.128	1.128	1.127	1.126	1.125	1.125	1.124	1.123	1.122
9.436	1.122	1.121	1.120	1.119	1.118	1.118	1.117	1.116	1.115	1.114
9.713	1.113	1.112	1.110	1.109	1.108	1.107	1.105	1.104	1.103	1.101
9.991	1.100	1.098	1.097	1.095	1.094	1.092	1.091	1.090	1.088	1.087
10.268	1.085	1.084	1.083	1.081	1.080	1.079	1.078	1.077	1.076	1.075
10.546	1.074	1.073	1.072	1.071	1.070	1.070	1.069	1.069	1.068	1.068
10.823	1.067	1.067	1.067	1.066	1.066	1.066	1.065	1.065	1.064	1.064
11.101	1.064	1.063	1.063	1.062	1.062	1.061	1.061	1.060	1.059	1.059
11.378	1.058	1.057	1.056	1.055	1.054	1.053	1.052	1.051	1.049	1.048
11.656	1.047	1.045	1.044	1.043	1.041	1.040	1.039	1.037	1.036	1.034
11.933	1.033	1.032	1.030	1.029	1.028	1.026	1.025	1.024	1.023	1.022
12.211	1.021	1.020	1.019	1.018	1.017	1.016	1.015	1.014	1.014	1.013
12.488	1.012	1.011	1.011	1.010	1.009	1.008	1.008	1.007	1.006	1.005
12.766	1.004	1.003	1.002	1.001	1.000	0.999	0.998	0.997	0.995	0.994
13.043	0.993	0.991	0.990	0.988	0.987	0.985	0.983	0.982	0.980	0.978
13.321	0.976	0.974	0.972	0.970	0.968	0.966	0.964	0.962	0.960	0.958
13.598	0.956	0.954	0.952	0.950	0.948	0.946	0.944	0.941	0.939	0.937
13.876	0.935	0.932	0.930	0.927	0.925					

TABLE B-8. E674 CALIBRATION, (u_p, t), PARTICLE VELOCITY VS. TIME, OBTAINED BY APPLYING EQUATION (3-7) TO DATA OF TABLE B-5

Time increment = 27.7885 ns
Number of points = 1357

μs	<———				Units:	km/s				———>
0.000	-	-	-	-	-	-	-	-	-	-
0.278	-	-	-	-	-	-	-	-	-	-
0.556	-	-	-	-	-	-	-	-	-	-
0.834	-	-	-	-	-	-	-	-	-	-
1.112	-	-	-	-	-	1.740	1.734	1.727	1.721	1.715
1.389	1.709	1.704	1.698	1.693	1.687	1.682	1.677	1.672	1.667	1.661
1.667	1.656	1.651	1.646	1.642	1.637	1.632	1.627	1.622	1.618	1.613
1.945	1.609	1.605	1.600	1.596	1.592	1.588	1.584	1.581	1.577	1.573
2.223	1.570	1.566	1.563	1.560	1.556	1.553	1.550	1.547	1.544	1.541
2.501	1.538	1.536	1.533	1.530	1.527	1.525	1.522	1.519	1.517	1.514
2.779	1.511	1.509	1.506	1.503	1.500	1.498	1.495	1.492	1.489	1.487
3.057	1.484	1.481	1.478	1.475	1.472	1.469	1.466	1.463	1.460	1.457
3.335	1.454	1.451	1.448	1.445	1.442	1.439	1.436	1.433	1.430	1.427
3.613	1.424	1.421	1.419	1.416	1.413	1.411	1.408	1.406	1.403	1.401
3.890	1.398	1.396	1.394	1.392	1.390	1.387	1.385	1.383	1.381	1.379
4.168	1.378	1.376	1.374	1.372	1.370	1.368	1.366	1.364	1.363	1.361
4.446	1.359	1.357	1.355	1.354	1.352	1.350	1.348	1.347	1.345	1.343
4.724	1.341	1.340	1.338	1.336	1.335	1.333	1.331	1.330	1.328	1.326
5.002	1.325	1.323	1.321	1.320	1.318	1.317	1.315	1.313	1.312	1.310
5.280	1.309	1.307	1.306	1.304	1.303	1.301	1.300	1.298	1.297	1.295
5.558	1.293	1.292	1.290	1.288	1.287	1.285	1.283	1.281	1.280	1.278
5.836	1.276	1.274	1.272	1.271	1.269	1.267	1.265	1.263	1.261	1.259
6.113	1.257	1.255	1.254	1.252	1.250	1.248	1.246	1.245	1.243	1.241
6.391	1.239	1.238	1.236	1.234	1.233	1.231	1.230	1.228	1.227	1.225
6.669	1.224	1.222	1.221	1.219	1.218	1.216	1.215	1.213	1.212	1.210
6.947	1.209	1.207	1.206	1.204	1.203	1.201	1.200	1.198	1.197	1.195
7.225	1.193	1.192	1.130	1.189	1.187	1.186	1.185	1.183	1.182	1.181
7.503	1.179	1.178	1.177	1.176	1.175	1.173	1.172	1.171	1.170	1.169
7.781	1.168	1.168	1.167	1.166	1.165	1.164	1.164	1.163	1.162	1.162
8.059	1.161	1.160	1.159	1.159	1.158	1.157	1.156	1.156	1.155	1.154
8.337	1.153	1.152	1.151	1.150	1.149	1.148	1.147	1.145	1.144	1.143
8.614	1.142	1.141	1.139	1.138	1.137	1.135	1.134	1.133	1.131	1.130
8.892	1.129	1.128	1.126	1.125	1.124	1.123	1.122	1.121	1.120	1.119
9.170	1.118	1.117	1.116	1.115	1.114	1.113	1.113	1.112	1.111	1.110
9.448	1.109	1.109	1.108	1.107	1.106	1.105	1.104	1.103	1.103	1.102
9.726	1.100	1.099	1.098	1.097	1.096	1.095	1.093	1.092	1.091	1.089
10.004	1.088	1.087	1.085	1.084	1.083	1.081	1.080	1.078	1.077	1.076
10.282	1.075	1.073	1.072	1.071	1.070	1.068	1.067	1.066	1.065	1.064
10.560	1.063	1.062	1.062	1.061	1.060	1.059	1.059	1.058	1.057	1.057
10.838	1.056	1.055	1.055	1.054	1.054	1.053	1.053	1.052	1.052	1.051
11.115	1.051	1.050	1.050	1.049	1.049	1.048	1.047	1.047	1.046	1.045
11.393	1.044	1.044	1.043	1.042	1.041	1.040	1.039	1.038	1.037	1.036
11.671	1.035	1.034	1.032	1.031	1.030	1.029	1.028	1.027	1.026	1.025
11.949	1.023	1.022	1.021	1.020	1.019	1.018	1.017	1.015	1.014	1.013
12.227	1.012	1.011	1.009	1.008	1.007	1.006	1.005	1.003	1.002	1.001
12.505	1.000	0.998	0.997	0.996	0.995	0.993	0.992	0.991	0.989	0.988
12.783	0.986	0.985	0.984	0.982	0.981	0.980	0.978	0.977	0.976	0.974
13.061	0.973	0.972	0.971	0.969	0.968	0.967	0.965	0.964	0.963	0.962
13.338	0.961	0.959	0.958	0.957	0.956	0.955	0.954	0.953	0.951	0.950
13.616	0.949	0.948	0.947	0.945	0.944	0.943	0.942	0.940	0.939	0.937
13.894	0.936	0.934	0.933	0.931	0.930	0.928	0.926	0.925	0.923	0.922
14.172	0.920	0.918	0.916	0.915	0.913	0.911	0.910	0.908	0.906	0.904
14.450	0.902	0.900	0.898	0.897	0.895	[illegible]	0.891	0.889	0.888	0.886
14.728	0.884	0.883	0.881	0.880	0.878	[illegible]	0.875	0.874	0.873	[illegible]
15.006	0.870	0.869	0.867	0.866	0.865	0.864	0.862	0.861	0.860	0.859
15.284	0.857	0.856	0.855	0.854	0.852	0.851	0.850	0.848	0.847	0.846
15.562	0.844	0.843	0.842	0.840	0.838	0.837	0.835	0.834	0.832	0.831
15.839	0.829	0.827	0.825	0.824	0.822	0.820	0.818	0.816	0.814	0.812
16.117	0.810	0.809	0.807	0.805	0.803	0.801	0.799	0.797	0.796	0.794

16.395	0.792	0.791	0.789	0.787	0.786	0.784	0.782	0.781	0.779	0.778
16.673	0.777	0.775	0.774	0.773	0.771	0.770	0.769	0.768	0.767	0.766
16.951	0.765	0.763	0.762	0.762	0.761	0.760	0.759	0.758	0.757	0.756
17.229	0.755	0.754	0.753	0.752	0.751	0.750	0.749	0.748	0.746	0.745
17.507	0.744	0.742	0.741	0.740	0.738	0.737	0.735	0.733	0.732	0.730
17.785	0.728	0.726	0.724	0.723	0.721	0.719	0.717	0.715	0.713	0.711
18.063	0.709	0.707	0.705	0.703	0.701	0.699	0.697	0.695	0.693	0.691
18.340	0.689	0.688	0.686	0.684	0.682	0.681	0.679	0.677	0.676	0.674
18.618	0.673	0.672	0.670	0.669	0.668	0.666	0.665	0.664	0.663	0.662
18.896	0.661	0.660	0.659	0.658	0.657	0.656	0.655	0.654	0.653	0.653
19.174	0.652	0.651	0.650	0.650	0.649	0.648	0.647	0.646	0.646	0.645
19.452	0.644	0.643	0.642	0.641	0.640	0.639	0.638	0.637	0.636	0.635
19.730	0.634	0.633	0.632	0.630	0.629	0.628	0.627	0.626	0.625	0.623
20.008	0.622	0.620	0.619	0.618	0.616	0.615	0.613	0.612	0.611	0.609
20.286	0.608	0.606	0.605	0.604	0.602	0.601	0.599	0.598	0.597	0.595
20.564	0.594	0.593	0.591	0.590	0.588	0.587	0.585	0.584	0.583	0.581
20.841	0.580	0.579	0.578	0.577	0.575	0.574	0.573	0.572	0.571	0.570
21.119	0.568	0.567	0.566	0.565	0.564	0.563	0.562	0.561	0.560	0.559
21.397	0.558	0.557	0.556	0.555	0.555	0.554	0.553	0.552	0.551	0.550
21.675	0.550	0.549	0.548	0.547	0.547	0.546	0.545	0.544	0.544	0.543
21.953	0.542	0.542	0.541	0.540	0.540	0.539	0.538	0.537	0.536	0.535
22.231	0.535	0.534	0.534	0.533	0.532	0.532	0.531	0.531	0.530	0.529
22.509	0.529	0.528	0.527	0.526	0.526	0.526	0.525	0.524	0.524	0.523
22.787	0.523	0.522	0.522	0.521	0.521	0.520	0.519	0.519	0.518	0.518
23.064	0.517	0.516	0.515	0.514	0.513	0.512	0.511	0.510	0.508	0.507
23.342	0.506	0.505	0.503	0.502	0.500	0.498	0.496	0.494	0.492	0.490
23.620	0.488	0.485	0.483	0.480	0.478	0.475	0.472	0.469	0.466	0.463
23.898	0.460	0.456	0.452	0.448	0.444	0.440	0.436	0.431	0.427	0.422
24.176	0.417	0.412	0.407	0.402	0.397	0.392	0.387	0.382	0.377	0.372
24.454	0.368	0.363	0.359	0.354	0.350	0.345	0.341	0.337	0.334	0.330
24.732	0.327	0.325	0.323	0.320	0.318	0.316	0.315	0.313	0.312	0.310
25.010	0.309	0.307	0.305	0.304	0.303	0.302	0.301	0.300	0.299	0.298
25.288	0.297	0.295	0.294	0.293	0.291	0.290	0.288	0.286	0.284	0.282
25.565	0.279	0.276	0.274	0.271	0.269	0.266	0.264	0.262	0.259	0.257
25.843	0.254	0.251	0.249	0.247	0.244	0.242	0.239	0.237	0.235	0.233
26.121	0.231	0.229	0.227	0.225	0.224	0.222	0.221	0.220	0.219	0.218
26.399	0.218	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.218	0.218
26.677	0.219	0.220	0.221	0.222	0.223	0.224	0.225	0.227	0.228	0.229
26.955	0.231	0.232	0.234	0.235	0.236	0.238	0.239	0.241	0.243	0.244
27.233	0.246	0.247	0.249	0.250	0.252	0.253	0.254	0.256	0.257	0.258
27.511	0.259	0.260	0.261	0.261	0.261	0.261	0.261	0.261	0.260	0.259
27.789	0.258	0.257	0.256	0.255	0.253	0.251	0.249	0.247	0.245	0.243
28.066	0.240	0.238	0.236	0.234	0.231	0.229	0.227	0.225	0.223	0.221
28.344	0.219	0.217	0.215	0.214	0.213	0.211	0.210	0.209	0.209	0.208
28.622	0.208	0.207	0.207	0.208	0.208	0.208	0.209	0.210	0.210	0.211
28.900	0.213	0.214	0.215	0.217	0.219	0.220	0.222	0.224	0.226	0.228
29.178	0.230	0.232	0.234	0.236	0.238	0.240	0.242	0.244	0.247	0.249
29.456	0.251	0.253	0.254	0.256	0.257	0.258	0.259	0.260	0.260	0.261
29.734	0.261	0.261	0.261	0.261	0.261	0.261	0.261	0.260	0.260	0.260
30.012	0.260	0.260	0.260	0.260	0.259	0.259	0.259	0.259	0.259	0.260
30.289	0.260	0.260	0.261	0.261	0.262	0.263	0.263	0.264	0.264	0.264
30.567	0.264	0.264	0.264	0.264	0.264	0.263	0.262	0.261	0.260	0.258
30.845	0.256	0.254	0.252	0.249	0.247	0.244	0.242	0.239	0.236	0.233
31.123	0.230	0.227	0.224	0.221	0.218	0.215	0.213	0.210	0.208	0.205
31.401	0.203	0.201	0.199	0.198	0.196	0.194	0.193	0.192	0.191	0.190
31.679	0.189	0.189	0.188	0.188	0.188	0.188	0.188	0.189	0.190	0.191
31.957	0.192	0.193	0.195	0.196	0.198	0.200	0.202	0.204	0.206	0.208
32.235	0.210	0.213	0.215	0.217	0.220	0.222	0.224	0.226	0.228	0.230
32.513	0.232	0.234	0.236	0.237	0.238	0.239	0.239	0.239	0.239	0.239
32.790	0.239	0.239	0.238	0.238	0.237	0.236	0.235	0.234	0.232	0.231
33.068	0.230	0.228	0.226	0.225	0.223	0.221	0.219	0.217	0.215	0.213
33.346	0.211	0.209	0.207	0.205	0.204	0.202	0.200	0.198	0.196	0.194
33.624	0.192	0.191	0.189	0.187	0.186	0.184	0.183	0.182	0.180	0.179
33.902	0.178	0.177	0.177	0.176	0.175	0.175	0.174	0.174	0.174	0.174
34.180	0.174	0.174	0.174	0.174	0.174	0.175	0.175	0.176	0.176	0.177
34.458	0.178	0.178	0.179	0.180	0.181	0.182	0.183	0.183	0.184	0.185
34.736	0.186	0.187	0.188	0.189	0.190	0.190	0.191	0.192	0.193	0.193
35.014	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.193	0.193	0.193
35.291	0.192	0.192	0.191	0.190	0.189	0.188	0.187	0.186	0.185	0.184
35.569	0.183	0.181	0.180	0.179	0.178	0.177	0.176	0.175	0.174	0.173
35.847	0.172	0.171	0.170	0.170	0.169	0.169	0.168	0.168	0.168	0.167

36.125	0.167	0.167	0.167	0.167	0.168	0.168	0.168	0.169	0.169	0.170
36.403	0.170	0.171	0.172	0.173	0.174	0.175	0.176	0.177	0.178	0.179
36.681	0.180	0.181	0.183	0.184	0.185	0.186	0.187	0.188	0.189	0.191
36.959	0.192	0.193	0.194	0.195	0.196	0.197	0.198	0.199	0.199	0.200
37.237	0.201	0.201	0.202	0.202	0.203	0.203	0.204	0.204	0.205	0.205
37.515	0.206	0.207	0.207	0.208	0.209	0.210	0.210			

TABLE B-9. E675 CALIBRATION, (u_p, t), PARTICLE VELOCITY VS. TIME, OBTAINED BY APPLYING EQUATION (3-7) TO DATA OF TABLE B-6

Time increment = 16.6725 ns
Number of points = 857

µs	<—— Units: km/s ——>									
0.000	-	-	-	-	-	-	-	-	-	-
0.167	-	-	-	-	-	-	-	-	-	-
0.333	-	-	-	-	-	-	-	-	-	-
0.500	-	-	-	-	-	-	-	-	-	-
0.667	-	-	-	-	-	1.755	1.753	1.750	1.748	1.746
0.834	1.745	1.743	1.742	1.740	1.738	1.737	1.735	1.733	1.732	1.730
1.000	1.728	1.726	1.724	1.722	1.719	1.717	1.715	1.713	1.710	1.708
1.167	1.705	1.703	1.700	1.697	1.695	1.692	1.689	1.636	1.683	1.680
1.334	1.677	1.674	1.671	1.668	1.665	1.662	1.659	1.656	1.653	1.650
1.501	1.647	1.644	1.641	1.638	1.636	1.633	1.630	1.627	1.625	1.622
1.667	1.620	1.617	1.615	1.613	1.610	1.608	1.606	1.604	1.602	1.600
1.834	1.598	1.596	1.594	1.592	1.590	1.588	1.587	1.585	1.583	1.581
2.001	1.579	1.577	1.575	1.574	1.572	1.570	1.568	1.566	1.564	1.562
2.167	1.560	1.558	1.556	1.554	1.552	1.550	1.548	1.546	1.543	1.541
2.334	1.539	1.537	1.535	1.533	1.530	1.528	1.526	1.524	1.522	1.519
2.501	1.517	1.515	1.513	1.511	1.509	1.507	1.505	1.503	1.501	1.499
2.668	1.497	1.495	1.493	1.492	1.490	1.488	1.486	1.485	1.483	1.481
2.834	1.480	1.479	1.477	1.475	1.474	1.473	1.471	1.470	1.469	1.467
3.001	1.466	1.465	1.463	1.462	1.461	1.460	1.458	1.457	1.456	1.455
3.168	1.454	1.452	1.451	1.450	1.449	1.447	1.446	1.445	1.443	1.442
3.334	1.441	1.439	1.438	1.436	1.435	1.433	1.432	1.430	1.429	1.427
3.501	1.425	1.424	1.422	1.421	1.419	1.418	1.416	1.415	1.414	1.412
3.668	1.411	1.409	1.408	1.407	1.405	1.404	1.403	1.402	1.401	1.400
3.835	1.399	1.398	1.397	1.396	1.395	1.394	1.393	1.392	1.392	1.391
4.001	1.390	1.389	1.388	1.388	1.387	1.386	1.385	1.384	1.384	1.383
4.168	1.382	1.381	1.379	1.378	1.377	1.376	1.375	1.374	1.372	1.371
4.335	1.369	1.368	1.366	1.365	1.364	1.362	1.360	1.359	1.357	1.356
4.502	1.354	1.353	1.351	1.350	1.348	1.347	1.345	1.344	1.342	1.341
4.668	1.339	1.337	1.336	1.335	1.333	1.331	1.330	1.329	1.327	1.326
4.835	1.324	1.323	1.321	1.320	1.318	1.316	1.315	1.314	1.312	1.311
5.002	1.309	1.308	1.306	1.304	1.303	1.301	1.300	1.298	1.297	1.296
5.168	1.294	1.293	1.291	1.290	1.289	1.288	1.286	1.285	1.284	1.283
5.335	1.282	1.281	1.280	1.280	1.279	1.278	1.278	1.277	1.277	1.276
5.502	1.276	1.275	1.275	1.275	1.275	1.275	1.274	1.274	1.274	1.274
5.669	1.273	1.273	1.273	1.272	1.272	1.271	1.271	1.270	1.270	1.269
5.835	1.269	1.268	1.267	1.267	1.266	1.265	1.264	1.263	1.262	1.261
6.002	1.260	1.258	1.257	1.256	1.255	1.254	1.252	1.251	1.250	1.249
6.169	1.247	1.246	1.245	1.244	1.243	1.241	1.240	1.239	1.238	1.237
6.336	1.236	1.235	1.234	1.233	1.232	1.231	1.230	1.229	1.227	1.226
6.502	1.225	1.224	1.223	1.222	1.221	1.220	1.219	1.218	1.217	1.216
6.669	1.215	1.214	1.213	1.212	1.211	1.210	1.209	1.208	1.207	1.206
6.836	1.205	1.204	1.203	1.202	1.201	1.201	1.200	1.199	1.198	1.197
7.002	1.196	1.195	1.195	1.194	1.193	1.192	1.192	1.191	1.190	1.190
7.169	1.189	1.189	1.188	1.188	1.187	1.187	1.186	1.186	1.186	1.185
7.336	1.185	1.185	1.185	1.184	1.184	1.184	1.183	1.183	1.183	1.183
7.503	1.182	1.182	1.182	1.181	1.181	1.181	1.180	1.180	1.179	1.179
7.669	1.178	1.178	1.177	1.177	1.176	1.175	1.174	1.174	1.173	1.172
7.836	1.171	1.170	1.169	1.168	1.167	1.166	1.165	1.164	1.163	1.162
8.003	1.160	1.159	1.158	1.157	1.156	1.154	1.153	1.152	1.151	1.150
8.170	1.148	1.147	1.146	1.145	1.143	1.142	1.141	1.140	1.139	1.138
8.336	1.136	1.135	1.134	1.133	1.132	1.131	1.130	1.130	1.129	1.128
8.503	1.127	1.127	1.126	1.125	1.125	1.124	1.123	1.123	1.122	1.122
8.670	1.122	1.121	1.121	1.121	1.120	1.120	1.120	1.120	1.119	1.119
8.836	1.119	1.119	1.119	1.119	1.119	1.119	1.119	1.119	1.119	1.118
9.003	1.118	1.118	1.118	1.117	1.117	1.117	1.116	1.116	1.116	1.115
9.170	1.115	1.114	1.114	1.113	1.112	1.111	1.111	1.110	1.109	1.108
9.337	1.107	1.106	1.106	1.105	1.104	1.103	1.102	1.101	1.100	1.100
9.503	1.099	1.098	1.097	1.097	1.096	1.095	1.095	1.094	1.094	1.093
9.670	1.093	1.092	1.092	1.092	1.091	1.091	1.090	1.090	1.090	1.089

9.837	1.089	1.089	1.088	1.088	1.088	1.087	1.087	1.086	1.086	1.085
10.004	1.084	1.083	1.083	1.082	1.081	1.080	1.079	1.078	1.077	1.077
10.170	1.076	1.075	1.074	1.073	1.072	1.071	1.070	1.069	1.068	1.067
10.337	1.067	1.066	1.065	1.064	1.064	1.063	1.062	1.062	1.061	1.061
10.504	1.060	1.060	1.060	1.059	1.059	1.059	1.059	1.059	1.058	1.058
10.670	1.058	1.058	1.058	1.058	1.058	1.058	1.057	1.057	1.057	1.057
10.837	1.057	1.057	1.057	1.056	1.056	1.056	1.056	1.055	1.055	1.055
11.004	1.054	1.054	1.053	1.053	1.052	1.052	1.052	1.051	1.051	1.050
11.171	1.050	1.049	1.049	1.048	1.048	1.047	1.047	1.046	1.046	1.045
11.337	1.045	1.044	1.044	1.043	1.043	1.042	1.042	1.041	1.041	1.040
11.504	1.040	1.039	1.039	1.038	1.038	1.038	1.037	1.037	1.036	1.036
11.671	1.035	1.035	1.034	1.034	1.033	1.032	1.032	1.031	1.031	1.030
11.837	1.029	1.029	1.028	1.027	1.027	1.026	1.025	1.024	1.024	1.023
12.004	1.022	1.021	1.020	1.020	1.019	1.018	1.017	1.016	1.015	1.014
12.171	1.013	1.012	1.011	1.010	1.009	1.008	1.007	1.006	1.005	1.004
12.338	1.003	1.002	1.001	1.000	0.999	0.998	0.997	0.997	0.996	0.995
12.504	0.994	0.993	0.993	0.992	0.992	0.991	0.991	0.990	0.990	0.989
12.671	0.989	0.988	0.988	0.988	0.988	0.987	0.987	0.986	0.986	0.986
12.838	0.985	0.985	0.985	0.984	0.984	0.983	0.983	0.982	0.982	0.981
13.005	0.980	0.979	0.979	0.978	0.977	0.976	0.975	0.973	0.972	0.971
13.171	0.969	0.968	0.966	0.964	0.963	0.961	0.959	0.958	0.956	0.954
13.338	0.952	0.950	0.949	0.947	0.945	0.943	0.941	0.940	0.938	0.937
13.505	0.935	0.934	0.932	0.931	0.930	0.928	0.927	0.926	0.925	0.924
13.671	0.923	0.922	0.921	0.920	0.919	0.918	0.917	0.916	0.915	0.914
13.838	0.913	0.912	0.910	0.909	0.907	0.906	0.904	0.902	0.900	0.898
14.005	0.896	0.893	0.891	0.888	0.885	0.883	0.880	0.877	0.874	0.871
14.172	0.868	0.864	0.861	0.858	0.855	0.852	0.849			

TABLE B-10. E673 CALIBRATION, (P, t), PRESSURE VS. TIME, OBTAINED FROM DATA OF TABLES B-4 AND B-7

Time increment = 27.7515 ns
Number of points = 505

μs	<————				Units:	GPa				————>
0.000	-	-	-	-	-	-	-	-	-	-
0.278	-	-	-	-	-	-	-	-	-	-
0.555	-	-	-	-	-	-	-	-	-	-
0.833	-	-	-	-	-	-	-	-	-	-
1.110	-	-	-	-	-	11.385	11.346	11.304	11.260	11.217
1.388	11.174	11.129	11.084	11.040	10.994	10.949	10.905	10.862	10.818	10.775
1.665	10.731	10.688	10.644	10.600	10.557	10.514	10.471	10.429	10.386	10.345
1.943	10.303	10.263	10.222	10.183	10.144	10.105	10.067	10.028	9.990	9.951
2.220	9.913	9.876	9.839	9.802	9.765	9.728	9.692	9.655	9.619	9.584
2.498	9.550	9.516	9.482	9.447	9.413	9.379	9.345	9.312	9.279	9.247
2.775	9.215	9.183	9.151	9.120	9.089	9.058	9.027	8.996	8.966	8.936
3.053	8.906	8.877	8.848	8.820	8.791	8.763	8.734	8.706	8.679	8.651
3.330	8.624	8.597	8.571	8.545	8.518	8.492	8.466	8.440	8.415	8.390
3.608	8.365	8.340	8.316	8.293	8.269	8.246	8.223	8.200	8.177	8.154
3.885	8.132	8.111	8.090	8.069	8.050	8.030	8.012	7.993	7.974	7.956
4.163	7.938	7.920	7.902	7.885	7.869	7.851	7.836	7.620	7.805	7.790
4.440	7.775	7.761	7.747	7.734	7.721	7.707	7.694	7.681	7.668	7.654
4.718	7.641	7.628	7.615	7.602	7.589	7.575	7.562	7.548	7.534	7.519
4.995	7.505	7.491	7.475	7.459	7.443	7.427	7.410	7.393	7.376	7.358
5.273	7.340	7.322	7.304	7.286	7.267	7.248	7.229	7.210	7.190	7.171
5.550	7.151	7.132	7.113	7.094	7.076	7.057	7.039	7.021	7.003	6.986
5.828	6.969	6.952	6.937	6.921	6.905	6.890	6.875	6.860	6.846	6.833
6.105	6.819	6.806	6.793	6.780	6.768	6.756	6.744	6.732	6.720	6.709
6.383	6.698	6.687	6.677	6.666	6.656	6.645	6.634	6.623	6.612	6.601
6.660	6.590	6.578	6.566	6.555	6.543	6.531	6.520	6.508	6.496	6.484
6.938	6.471	6.459	6.447	6.435	6.423	6.411	6.399	6.387	6.375	6.364
7.215	6.352	6.341	6.330	6.319	6.308	6.298	6.288	6.278	6.268	6.259
7.493	6.250	6.241	6.233	6.224	6.216	6.209	6.201	6.194	6.186	6.180
7.770	6.173	6.167	6.160	6.154	6.147	6.140	6.133	6.127	6.120	6.113
8.048	6.106	6.099	6.092	6.084	6.077	6.070	6.062	6.054	6.046	6.038
8.325	6.029	6.021	6.012	6.004	5.996	5.987	5.979	5.970	5.961	5.952
8.603	5.944	5.935	5.926	5.917	5.909	5.901	5.893	5.885	5.877	5.869
8.880	5.861	5.854	5.847	5.839	5.832	5.826	5.819	5.812	5.805	5.799
9.158	5.792	5.786	5.781	5.775	5.769	5.764	5.758	5.753	5.747	5.742
9.436	5.736	5.730	5.724	5.717	5.711	5.704	5.698	5.690	5.683	5.676
9.713	5.667	5.659	5.650	5.641	5.631	5.621	5.612	5.601	5.591	5.580
9.991	5.570	5.559	5.548	5.537	5.526	5.515	5.504	5.493	5.483	5.472
10.268	5.462	5.452	5.442	5.432	5.423	5.414	5.406	5.397	5.389	5.382
10.546	5.375	5.368	5.362	5.356	5.351	5.346	5.342	5.338	5.334	5.331
10.823	5.328	5.325	5.322	5.320	5.317	5.315	5.312	5.309	5.306	5.304
11.101	5.301	5.298	5.294	5.290	5.287	5.283	5.279	5.275	5.270	5.264
11.378	5.258	5.252	5.246	5.238	5.231	5.223	5.214	5.205	5.196	5.187
11.656	5.177	5.167	5.157	5.147	5.137	5.127	5.117	5.107	5.096	5.087
11.933	5.077	5.067	5.057	5.047	5.038	5.029	5.021	5.012	5.004	4.997
12.211	4.989	4.982	4.976	4.969	4.962	4.956	4.950	4.944	4.938	4.932
12.488	4.927	4.922	4.916	4.911	4.905	4.900	4.834	4.888	4.882	4.876
12.766	4.870	4.864	4.856	4.849	4.842	4.834	4.826	4.818	4.808	4.799
13.043	4.789	4.779	4.769	4.758	4.747	4.736	4.724	4.712	4.700	4.687
13.321	4.675	4.662	4.648	4.634	4.620	4.606	4.592	4.578	4.565	4.551
13.598	4.537	4.522	4.508	4.494	4.479	4.465	4.451	4.436	4.422	4.407
13.876	4.392	4.376	4.359	4.341	4.324					

TABLE B-11. E674 CALIBRATION, (P, t), PRESSURE VS. TIME, OBTAINED FROM DATA OF TABLES B-5 AND B-8

Time increment = 27.7885 NS
Number of points = 1357

µs	<———————— Units:	GPa ————————>								
0.000	-	-	-	-	-	-	-	-	-	-
0.278	-	-	-	-	-	-	-	-	-	-
0.556	-	-	-	-	-	-	-	-	-	-
0.834	-	-	-	-	-	-	-	-	-	-
1.112	-	-	-	-	-	11.288	11.223	11.158	11.096	11.034
1.389	10.976	10.918	10.862	10.809	10.756	10.704	10.652	10.599	10.548	10.497
1.667	10.447	10.397	10.348	10.299	10.252	10.204	10.158	10.112	10.067	10.024
1.945	9.981	9.939	9.898	9.858	9.819	9.781	9.743	9.707	9.672	9.637
2.223	9.603	9.569	9.536	9.505	9.474	9.444	9.415	9.386	9.358	9.330
2.501	9.304	9.278	9.252	9.226	9.200	9.175	9.150	9.125	9.100	9.076
2.779	9.050	9.025	8.999	8.974	8.949	8.923	8.898	8.872	8.846	8.820
3.057	8.795	8.768	8.740	8.713	8.686	8.658	8.630	8.603	8.575	8.547
3.335	8.519	8.491	8.463	8.436	8.410	8.383	8.356	8.330	8.305	8.279
3.613	8.254	8.229	8.204	8.180	8.156	8.133	8.110	8.088	8.066	8.045
3.890	8.023	8.003	7.983	7.964	7.944	7.925	7.907	7.889	7.872	7.855
4.168	7.839	7.822	7.806	7.789	7.772	7.756	7.739	7.723	7.708	7.692
4.446	7.677	7.661	7.646	7.630	7.615	7.600	7.585	7.570	7.555	7.540
4.724	7.525	7.510	7.496	7.481	7.466	7.451	7.437	7.423	7.408	7.394
5.002	7.380	7.367	7.353	7.339	7.325	7.312	7.298	7.285	7.272	7.259
5.280	7.246	7.233	7.220	7.208	7.195	7.182	7.169	7.156	7.143	7.130
5.558	7.116	7.102	7.087	7.074	7.059	7.045	7.029	7.015	7.000	6.985
5.836	6.970	6.954	6.939	6.924	6.909	6.893	6.878	6.862	6.847	6.831
6.113	6.815	6.799	6.784	6.768	6.754	6.738	6.724	6.710	6.696	6.681
6.391	6.667	6.654	6.641	6.627	6.614	6.601	6.588	6.575	6.563	6.551
6.669	6.539	6.527	6.515	6.502	6.490	6.478	6.466	6.454	6.442	6.431
6.947	6.419	6.407	6.395	6.383	6.371	6.359	6.346	6.334	6.321	6.309
7.225	6.296	6.284	6.272	6.260	6.249	6.237	6.226	6.215	6.204	6.194
7.503	6.184	6.175	6.165	6.155	6.146	6.137	6.129	6.120	6.112	6.105
7.781	6.098	6.091	6.085	6.079	6.073	6.066	6.061	6.055	6.050	6.045
8.059	6.039	6.033	6.028	6.023	6.017	6.011	6.004	5.998	5.991	5.985
8.337	5.977	5.969	5.961	5.954	5.945	5.937	5.928	5.919	5.910	5.900
8.614	5.891	5.881	5.872	5.861	5.851	5.840	5.830	5.820	5.810	5.800
8.892	5.791	5.781	5.772	5.763	5.754	5.745	5.737	5.729	5.721	5.714
9.170	5.707	5.700	5.693	5.686	5.679	5.673	5.667	5.661	5.655	5.649
9.448	5.643	5.637	5.631	5.625	5.618	5.611	5.605	5.598	5.591	5.583
9.726	5.574	5.566	5.558	5.549	5.540	5.532	5.522	5.512	5.502	5.492
10.004	5.482	5.472	5.462	5.451	5.441	5.431	5.421	5.410	5.400	5.390
10.282	5.381	5.371	5.362	5.353	5.344	5.335	5.327	5.319	5.312	5.304
10.560	5.297	5.291	5.285	5.279	5.273	5.268	5.263	5.258	5.253	5.249
10.838	5.245	5.240	5.236	5.232	5.229	5.225	5.222	5.218	5.215	5.211
11.115	5.207	5.203	5.199	5.194	5.189	5.184	5.180	5.175	5.170	5.164
11.393	5.159	5.153	5.147	5.141	5.134	5.126	5.119	5.112	5.104	5.097
11.671	5.089	5.081	5.072	5.064	5.056	5.048	5.040	5.032	5.024	5.016
11.949	5.008	5.000	4.992	4.983	4.975	4.967	4.959	4.950	4.942	4.933
12.227	4.924	4.916	4.908	4.899	4.891	4.882	4.874	4.865	4.856	4.848
12.505	4.839	4.830	4.821	4.812	4.802	4.793	4.784	4.775	4.765	4.755
12.783	4.746	4.737	4.727	4.718	4.708	4.699	4.690	4.680	4.671	4.662
13.061	4.653	4.644	4.635	4.626	4.617	4.609	4.600	4.591	4.583	4.574
13.338	4.566	4.559	4.550	4.542	4.535	4.527	4.520	4.512	4.504	4.496
13.616	4.488	4.480	4.471	4.463	4.454	4.445	4.436	4.427	4.418	4.408
13.894	4.398	4.388	4.378	4.368	4.357	4.346	4.335	4.325	4.314	4.303
14.172	4.292	4.280	4.268	4.257	4.246	4.235	4.223	4.211	4.199	4.187
14.450	4.175	4.162	4.150	4.138	4.125	4.113	4.102	4.090	4.079	4.068
14.728	4.058	4.047	4.037	4.027	4.018	4.008	3.999	3.991	3.982	3.973
15.006	3.965	3.956	3.948	3.940	3.933	3.925	3.917	3.909	3.901	3.893
15.284	3.885	3.877	3.869	3.861	3.853	3.845	3.837	3.829	3.820	3.812
15.562	3.803	3.795	3.786	3.776	3.767	3.757	3.747	3.738	3.728	3.718
15.839	3.707	3.697	3.686	3.675	3.663	3.652	3.641	3.629	3.617	3.605
16.117	3.594	3.582	3.571	3.560	3.548	3.537	3.526	3.515	3.505	3.494
16.395	3.484	3.474	3.465	3.455	3.445	3.435	3.426	3.417	3.408	3.400
16.673	3.392	3.384	3.376	3.368	3.360	3.353	3.346	3.339	3.333	3.327

16.951	3.321	3.314	3.308	3.303	3.298	3.292	3.287	3.281	3.276	3.270
17.229	3.265	3.259	3.254	3.248	3.242	3.236	3.229	3.223	3.216	3.209
17.507	3.201	3.193	3.185	3.177	3.168	3.159	3.150	3.141	3.131	3.121
17.785	3.111	3.101	3.091	3.081	3.070	3.060	3.049	3.038	3.027	3.016
18.063	3.005	2.994	2.983	2.972	2.961	2.950	2.939	2.929	2.918	2.908
18.340	2.898	2.888	2.879	2.869	2.860	2.851	2.842	2.834	2.825	2.818
18.618	2.811	2.804	2.796	2.789	2.783	2.776	2.769	2.763	2.758	2.752
18.896	2.747	2.742	2.737	2.732	2.727	2.721	2.717	2.712	2.708	2.704
19.174	2.700	2.696	2.692	2.688	2.683	2.679	2.675	2.671	2.667	2.663
19.452	2.658	2.653	2.648	2.643	2.638	2.633	2.628	2.622	2.617	2.611
19.730	2.606	2.601	2.595	2.589	2.584	2.578	2.572	2.566	2.560	2.553
20.008	2.546	2.539	2.532	2.525	2.518	2.511	2.504	2.497	2.490	2.483
20.286	2.476	2.469	2.463	2.456	2.449	2.442	2.435	2.428	2.422	2.415
20.564	2.408	2.401	2.394	2.387	2.380	2.373	2.367	2.360	2.354	2.348
20.841	2.342	2.337	2.331	2.325	2.319	2.313	2.307	2.302	2.296	2.291
21.119	2.286	2.281	2.275	2.270	2.265	2.260	2.255	2.250	2.246	2.242
21.397	2.238	2.233	2.229	2.225	2.221	2.216	2.213	2.209	2.205	2.201
21.675	2.197	2.194	2.191	2.187	2.184	2.181	2.177	2.174	2.171	2.167
21.953	2.164	2.161	2.157	2.154	2.151	2.148	2.145	2.141	2.137	2.133
22.231	2.129	2.126	2.124	2.121	2.118	2.115	2.112	2.110	2.108	2.105
22.509	2.101	2.098	2.095	2.092	2.090	2.088	2.085	2.083	2.080	2.078
22.787	2.075	2.073	2.071	2.069	2.066	2.063	2.060	2.058	2.055	2.052
23.064	2.049	2.045	2.040	2.035	2.030	2.026	2.021	2.017	2.011	2.005
23.342	2.000	1.994	1.988	1.981	1.974	1.966	1.957	1.949	1.939	1.929
23.620	1.920	1.910	1.899	1.888	1.877	1.865	1.852	1.839	1.827	1.814
23.898	1.800	1.785	1.769	1.752	1.734	1.717	1.699	1.681	1.661	1.641
24.176	1.620	1.600	1.580	1.560	1.540	1.520	1.499	1.479	1.459	1.439
24.454	1.420	1.402	1.384	1.366	1.348	1.329	1.313	1.298	1.284	1.270
24.732	1.258	1.247	1.238	1.230	1.222	1.214	1.207	1.201	1.195	1.189
25.010	1.182	1.176	1.169	1.163	1.159	1.156	1.152	1.148	1.144	1.140
25.288	1.135	1.130	1.125	1.119	1.114	1.107	1.099	1.091	1.083	1.075
25.565	1.065	1.054	1.045	1.035	1.024	1.014	1.005	0.996	0.986	0.976
25.843	0.965	0.955	0.945	0.936	0.927	0.916	0.906	0.897	0.888	0.880
26.121	0.872	0.865	0.857	0.850	0.845	0.839	0.834	0.830	0.826	0.824
26.399	0.821	0.813	0.817	0.816	0.816	0.816	0.817	0.819	0.820	0.823
26.677	0.826	0.831	0.834	0.838	0.842	0.846	0.851	0.856	0.861	0.867
26.955	0.873	0.879	0.885	0.890	0.895	0.900	0.907	0.914	0.921	0.927
27.233	0.933	0.939	0.945	0.950	0.956	0.962	0.967	0.973	0.977	0.981
27.511	0.985	0.988	0.991	0.993	0.993	0.993	0.993	0.992	0.990	0.987
27.789	0.983	0.978	0.973	0.968	0.962	0.955	0.946	0.938	0.929	0.920
28.066	0.911	0.902	0.893	0.884	0.875	0.866	0.857	0.849	0.841	0.833
28.344	0.825	0.818	0.811	0.806	0.800	0.796	0.791	0.788	0.785	0.783
28.622	0.781	0.780	0.780	0.780	0.782	0.784	0.786	0.788	0.792	0.796
28.900	0.800	0.806	0.811	0.818	0.825	0.832	0.838	0.846	0.853	0.862
29.178	0.870	0.879	0.887	0.895	0.903	0.911	0.918	0.927	0.935	0.944
29.456	0.952	0.959	0.966	0.971	0.976	0.981	0.985	0.988	0.991	0.992
29.734	0.994	0.995	0.994	0.993	0.992	0.992	0.991	0.990	0.989	0.988
30.012	0.988	0.988	0.988	0.987	0.986	0.985	0.985	0.986	0.986	0.987
30.289	0.989	0.990	0.992	0.995	0.998	0.999	1.001	1.003	1.004	1.006
30.567	1.007	1.007	1.007	1.005	1.004	1.001	0.998	0.993	0.987	0.982
30.845	0.974	0.965	0.956	0.947	0.937	0.927	0.916	0.905	0.893	0.882
31.123	0.869	0.857	0.845	0.834	0.823	0.811	0.801	0.790	0.781	0.772
31.401	0.763	0.755	0.748	0.741	0.734	0.728	0.722	0.717	0.714	0.710
31.679	0.708	0.706	0.704	0.703	0.703	0.703	0.704	0.707	0.710	0.714
31.957	0.718	0.724	0.729	0.736	0.742	0.750	0.757	0.765	0.774	0.782
32.235	0.792	0.801	0.810	0.819	0.828	0.837	0.846	0.855	0.863	0.871
32.513	0.879	0.887	0.893	0.898	0.902	0.905	0.906	0.907	0.906	0.906
32.790	0.906	0.904	0.902	0.899	0.896	0.893	0.888	0.884	0.879	0.874
33.068	0.868	0.862	0.855	0.848	0.841	0.834	0.826	0.818	0.810	0.802
33.346	0.795	0.787	0.779	0.772	0.764	0.757	0.750	0.743	0.735	0.728
33.624	0.720	0.713	0.706	0.700	0.695	0.689	0.684	0.678	0.673	0.668
33.902	0.664	0.661	0.657	0.654	0.652	0.650	0.648	0.647	0.647	0.646
34.180	0.646	0.646	0.647	0.647	0.648	0.650	0.652	0.654	0.656	0.659
34.458	0.662	0.665	0.668	0.671	0.674	0.678	0.682	0.685	0.688	0.692
34.736	0.696	0.699	0.703	0.706	0.710	0.713	0.716	0.719	0.721	0.723
35.014	0.725	0.726	0.727	0.728	0.727	0.727	0.725	0.724	0.723	0.721
35.291	0.720	0.717	0.715	0.711	0.708	0.704	0.700	0.695	0.691	0.686
35.569	0.681	0.677	0.672	0.667	0.663	0.658	0.654	0.650	0.646	0.643
35.847	0.639	0.636	0.633	0.631	0.629	0.627	0.625	0.623	0.622	0.621
36.125	0.620	0.620	0.621	0.621	0.623	0.624	0.625	0.626	0.628	0.630
36.403	0.633	0.636	0.640	0.643	0.647	0.651	0.655	0.659	0.664	0.668

36.681	0.672	0.677	0.681	0.686	0.691	0.695	0.700	0.704	0.709	0.713
36.959	0.717	0.722	0.727	0.731	0.734	0.738	0.742	0.745	0.748	0.751
37.237	0.754	0.756	0.758	0.760	0.762	0.764	0.766	0.767	0.769	0.771
37.515	0.774	0.776	0.779	0.782	0.785	0.789	0.792			

TABLE B-12. E675 CALIBRATION, (P, t), PRESSURE VS. TIME, OBTAINED FROM DATA OF TABLES B-6 AND B-9

Time increment = 16.6725 ns
Number of points = 857

μs	<———				Units:	GPa				———>
0.000	-	-	-	-	-	-	-	-	-	-
0.167	-	-	-	-	-	-	-	-	-	-
0.333	-	-	-	-	-	-	-	-	-	-
0.500	-	-	-	-	-	-	-	-	-	-
0.667	-	-	-	-	-	11.445	11.418	11.393	11.373	11.355
0.834	11.339	11.322	11.305	11.288	11.271	11.254	11.237	11.219	11.202	11.183
1.000	11.164	11.143	11.122	11.100	11.079	11.056	11.033	11.009	10.985	10.960
1.167	10.935	10.909	10.883	10.856	10.828	10.799	10.771	10.743	10.715	10.685
1.334	10.655	10.625	10.595	10.564	10.534	10.504	10.474	10.444	10.413	10.384
1.501	10.354	10.326	10.297	10.269	10.241	10.214	10.187	10.160	10.135	10.110
1.667	10.086	10.062	10.039	10.017	9.995	9.973	9.952	9.931	9.912	9.892
1.834	9.873	9.854	9.834	9.816	9.799	9.781	9.764	9.746	9.728	9.710
2.001	9.692	9.675	9.657	9.639	9.622	9.604	9.586	9.568	9.549	9.531
2.167	9.512	9.492	9.473	9.453	9.433	9.413	9.392	9.372	9.351	9.331
2.334	9.311	9.291	9.270	9.249	9.229	9.208	9.187	9.166	9.146	9.125
2.501	9.104	9.083	9.063	9.043	9.024	9.006	8.987	8.969	8.951	8.934
2.668	8.917	8.900	8.883	8.866	8.850	8.834	8.818	8.803	8.788	8.773
2.834	8.759	8.744	8.731	8.718	8.705	8.692	8.680	8.668	8.656	8.644
3.001	8.632	8.620	8.608	8.596	8.585	8.573	8.562	8.551	8.540	8.528
3.168	8.517	8.506	8.495	8.484	8.472	8.461	8.449	8.437	8.425	8.413
3.334	8.400	8.387	8.373	8.360	8.347	8.333	8.319	8.306	8.292	8.278
3.501	8.264	8.251	8.237	8.224	8.210	8.197	8.184	8.171	8.158	8.145
3.668	8.133	8.120	8.108	8.096	8.085	8.074	8.063	8.053	8.043	8.034
3.835	8.025	8.017	8.009	8.001	7.993	7.985	7.977	7.970	7.963	7.956
4.001	7.948	7.942	7.935	7.928	7.921	7.914	7.906	7.899	7.891	7.883
4.168	7.874	7.865	7.856	7.846	7.836	7.825	7.814	7.803	7.792	7.780
4.335	7.767	7.755	7.742	7.729	7.716	7.703	7.689	7.676	7.662	7.648
4.502	7.635	7.621	7.607	7.594	7.582	7.569	7.557	7.544	7.530	7.517
4.668	7.504	7.491	7.478	7.466	7.452	7.439	7.426	7.414	7.401	7.389
4.835	7.376	7.362	7.349	7.337	7.324	7.311	7.298	7.286	7.274	7.261
5.002	7.248	7.235	7.221	7.208	7.195	7.183	7.170	7.158	7.146	7.134
5.168	7.122	7.110	7.098	7.087	7.077	7.066	7.056	7.047	7.038	7.030
5.335	7.022	7.014	7.007	7.000	6.993	6.988	6.983	6.978	6.974	6.971
5.502	6.967	6.964	6.962	6.960	6.959	6.957	6.955	6.954	6.952	6.950
5.669	6.947	6.944	6.941	6.938	6.934	6.931	6.927	6.922	6.918	6.913
5.835	6.908	6.903	6.897	6.891	6.884	6.876	6.869	6.860	6.852	6.842
6.002	6.833	6.824	6.814	6.804	6.795	6.784	6.774	6.764	6.753	6.743
6.169	6.733	6.723	6.713	6.703	6.693	6.684	6.675	6.666	6.657	6.648
6.336	6.639	6.631	6.622	6.614	6.605	6.596	6.588	6.579	6.570	6.561
6.502	6.553	6.544	6.536	6.527	6.519	6.511	6.503	6.495	6.487	6.478
6.669	6.469	6.461	6.452	6.444	6.436	6.428	6.420	6.412	6.404	6.397
6.836	6.390	6.382	6.375	6.368	6.360	6.353	6.347	6.339	6.332	6.325
7.002	6.318	6.311	6.305	6.299	6.294	6.288	6.283	6.277	6.272	6.267
7.169	6.262	6.258	6.254	6.249	6.246	6.243	6.240	6.237	6.235	6.233
7.336	6.230	6.228	6.225	6.223	6.220	6.218	6.216	6.214	6.212	6.210
7.503	6.208	6.206	6.203	6.201	6.198	6.195	6.192	6.189	6.185	6.181
7.669	6.177	6.173	6.167	6.162	6.157	6.151	6.146	6.140	6.133	6.127
7.836	6.120	6.113	6.105	6.098	6.090	6.081	6.072	6.063	6.054	6.045
8.003	6.036	6.027	6.018	6.008	5.999	5.989	5.979	5.970	5.960	5.951
8.170	5.941	5.932	5.922	5.912	5.903	5.893	5.884	5.875	5.866	5.858
8.336	5.849	5.841	5.833	5.825	5.817	5.810	5.803	5.797	5.790	5.784
8.503	5.779	5.773	5.768	5.763	5.758	5.754	5.749	5.745	5.742	5.738
8.670	5.735	5.733	5.730	5.727	5.725	5.723	5.721	5.720	5.719	5.718
8.836	5.718	5.717	5.717	5.716	5.715	5.714	5.714	5.714	5.712	5.711
9.003	5.709	5.708	5.706	5.704	5.701	5.699	5.696	5.693	5.690	5.686
9.170	5.683	5.679	5.674	5.669	5.663	5.658	5.653	5.647	5.640	5.634
9.337	5.627	5.620	5.613	5.606	5.600	5.593	5.586	5.580	5.574	5.568
9.503	5.562	5.556	5.551	5.546	5.541	5.537	5.532	5.528	5.525	5.521
9.670	5.518	5.514	5.511	5.508	5.505	5.502	5.499	5.496	5.494	5.492
9.837	5.489	5.487	5.484	5.481	5.478	5.474	5.471	5.467	5.463	5.458
10.004	5.453	5.447	5.442	5.436	5.429	5.422	5.416	5.409	5.402	5.396

10.170	5.389	5.382	5.375	5.367	5.361	5.354	5.347	5.340	5.334	5.328
10.337	5.323	5.317	5.311	5.305	5.300	5.295	5.290	5.286	5.282	5.279
10.504	5.276	5.274	5.271	5.269	5.267	5.265	5.264	5.262	5.261	5.261
10.670	5.260	5.259	5.258	5.257	5.256	5.255	5.255	5.254	5.253	5.252
10.837	5.251	5.249	5.248	5.246	5.245	5.243	5.241	5.239	5.237	5.234
11.004	5.232	5.229	5.225	5.222	5.218	5.215	5.211	5.208	5.204	5.200
11.171	5.197	5.194	5.190	5.186	5.183	5.179	5.175	5.171	5.168	5.165
11.337	5.162	5.159	5.155	5.152	5.148	5.145	5.142	5.138	5.134	5.131
11.504	5.127	5.123	5.120	5.116	5.113	5.110	5.107	5.104	5.100	5.097
11.671	5.093	5.089	5.085	5.081	5.077	5.073	5.069	5.064	5.060	5.056
11.837	5.051	5.046	5.042	5.037	5.031	5.025	5.020	5.014	5.009	5.004
12.004	4.998	4.992	4.987	4.980	4.974	4.967	4.961	4.954	4.947	4.940
12.171	4.933	4.927	4.920	4.913	4.905	4.899	4.891	4.884	4.877	4.870
12.338	4.863	4.856	4.849	4.843	4.836	4.829	4.823	4.816	4.811	4.805
12.504	4.800	4.795	4.790	4.785	4.781	4.778	4.774	4.771	4.768	4.765
12.671	4.763	4.760	4.758	4.756	4.754	4.751	4.748	4.746	4.743	4.741
12.838	4.739	4.736	4.734	4.731	4.727	4.724	4.721	4.717	4.712	4.707
13.005	4.702	4.697	4.691	4.684	4.678	4.670	4.663	4.654	4.646	4.636
13.171	4.625	4.615	4.604	4.593	4.582	4.570	4.558	4.546	4.534	4.522
13.338	4.510	4.497	4.484	4.472	4.460	4.448	4.436	4.424	4.414	4.403
13.505	4.393	4.384	4.374	4.365	4.356	4.347	4.339	4.332	4.325	4.319
13.671	4.313	4.307	4.301	4.294	4.288	4.281	4.274	4.267	4.260	4.252
13.838	4.245	4.237	4.228	4.219	4.208	4.197	4.185	4.173	4.159	4.146
14.005	4.131	4.116	4.099	4.082	4.065	4.047	4.028	4.009	3.990	3.970
14.172	3.950	3.930	3.909	3.890	3.870	3.850	3.831			

APPENDIX C

THE NERD FILTER

The Nearly Equal Ripple Derivative (NERD) filter was developed by Kaiser and Read.[C-1] If the derivative data are written as y_n and the original data as x_n then they show that

$$y_n = \sum_{k=1-N_p}^{N_p} b_k x_{n-k} \tag{C-1}$$

where $b_k = -b_{1-k}$ and $k = 1, 2, 3..., N_p$.

Thus the resulting filter is defined as

$$y_n = b_1(x_{n-1} - x_n) + b_2(x_{n-2} - x_{n+1}) + \ldots + b_{N_p}(x_{n-N_p} - x_{n+N_p-1}) \tag{C-2}$$

Design of the filter

First the parameters β, δ, and ϵ are specified as discussed earlier. Then we define λ where

$$\lambda = -20\log_{10}\epsilon \tag{C-3}$$

Then the parameter K_f is defined as

$$K_f = \begin{cases} 0.13927(\lambda - 7.95) & \lambda > 21 \\ 1.8445 & \lambda < 21 \end{cases} \tag{C-4}$$

[C-1] Kaiser, J. F. and Reed, W. A., "Data smoothing using low-pass digital filters," Rev. Sci. Inst., Vol. 48, No. 11, Nov 1987, p. 1447, and Vol. 49, No. 8, Aug 1978, p. 1103.

and

$$N_p = \mathit{Integer\ part\ of}\ [\frac{K_f}{2\delta} + 0.75] \tag{C-5}$$

Now an additional parameter η is defined as

$$\eta = \begin{cases} 0.1102(\lambda - 8.7) & 50 < \lambda \\ 0.5842(\lambda - 21)^{0.4} + 0.07886(\lambda - 21) & 21 < \lambda < 50 \\ 0 & \lambda < 21 \end{cases} \tag{C-6}$$

Finally, the filter coefficients b_k are defined as

$$b_k = b_{1-k} = \frac{1}{m}(-\beta \cos \beta m\pi + \frac{\sin \beta m\pi}{m\pi}) \times \left\{ \frac{I_0\left(\eta\sqrt{1 - (m/N_p)^2}\right)}{I_0(\eta)} \right\} \tag{C-7}$$

where $m = (2k - 1)/2$, $k = 1, 2, ..., N_p$, and $I_0(x)$ is a modified Bessel function,

$$I_0(x) = 1 + \sum_{k=1}^{\infty} \left[\frac{(x/2)^k}{k!} \right]^2 \tag{C-8}$$

The resulting filter will have a frequency response characteristic that has very nearly equal ripple about the unit slope line in the passband. In other words, if υ is frequency, $0 < \upsilon < \beta - \delta/2$, and about 0 in the stop band, $\beta + \delta/2 < \upsilon < 1$. For an exact unity slope the filter coefficients are multiplied by the factor

$$\left[\sum_{k=1}^{N_p} (2k - 1) b_k \right]^{-1} \tag{C-9}$$

Kaiser and Reed provided Fortran subroutines for Equations (C-3) to (C-9) in their paper. For this report these formulae were written as C functions;[C-1] they are reproduced in Appendix E.

[C-1] Microsoft 5.1, for DOS 3.0 and higher.

APPENDIX D

INDEPENDENT TEST OF DATA REDUCTION TECHNIQUES

The data reduction techniques reported here were independently compared with more conventional spline-fitting techniques by Sandusky and Groves.[D-1] They read the photographic records of this work using a different trace-reading apparatus than the one described here. Subsequently, they reduced the data to shock velocity, particle velocity, and pressure using more conventional spline-fitting techniques. The same PMMA shock Hugoniot was used, i.e., Equations (3-6) and (3-7) of the main text. In this way every aspect of the data reduction methods reported here was verified independently in an unbiased way. The results of the two methods were not compared until after the analyses had been completed.

The results of the independent tests are shown in Table D-1. Both the results of the NERD filtered data, from Table 3-2, and the spline-fitting are plotted in Figure D-1. The data are in agreement to within 2 percent although the NERD data are generally slightly higher in pressure.

[D-1] Sandusky, H. and Groves, C., private communication, NSWC, Code R13, White Oak, MD, concerning calculation of pressure data, 6 Apr 1989.

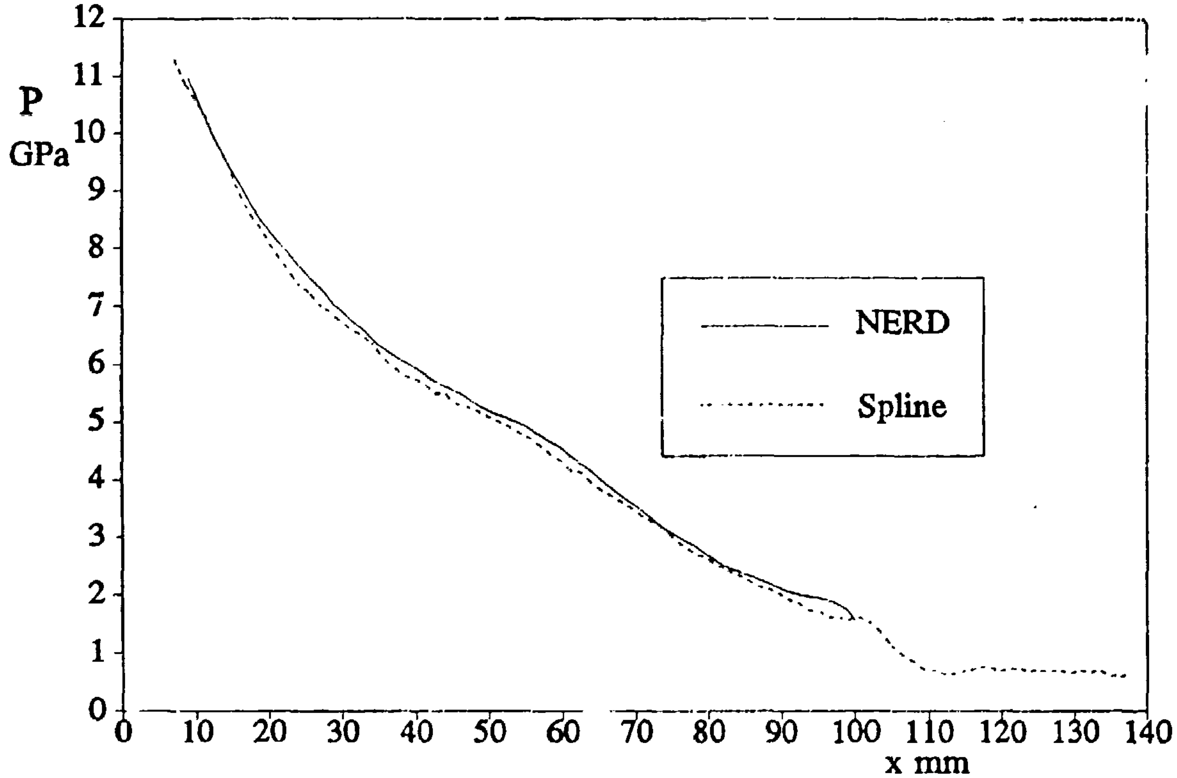

FIGURE D-1. COMPARISON OF PRESSURE VS. DISTANCE DATA OBTAINED BY NERD FILTERING AND SPLINE-FITTING

TABLE D-1. INDEPENDENT CALCULATION OF PRESSURE BY SPLINE-FITTING

x mm	P GPa	x mm	P GPa	x mm	P GPa
7.115	11.29	**51.130**	5.01	**95.122**	1.71
8.529	10.86	**52.521**	4.93	**96.553**	1.61
9.949	10.60	**53.969**	4.80	**97.973**	1.60
11.306	10.30	**55.395**	4.72	**99.398**	1.58
12.788	9.83	**56.809**	4.60	**100.840**	1.61
14.231	9.47	**58.223**	4.45	**102.220**	1.51
15.633	9.03	**59.642**	4.32	**103.640**	1.32
17.076	8.66	**61.073**	4.15	**105.071**	1.11
18.478	8.45	**62.470**	4.11	**106.513**	0.96
19.915	8.12	**63.890**	3.95	**107.916**	0.85
21.300	7.85	**65.321**	3.79	**109.336**	0.72
22.720	7.59	**66.752**	3.70	**110.738**	0.69
24.140	7.37	**68.154**	3.60	**112.169**	0.64
25.580	7.23	**69.585**	3.48	**113.595**	0.64
26.985	7.00	**71.011**	3.34	**115.009**	0.70
28.416	6.90	**72.436**	3.25	**116.428**	0.73
29.818	6.73	**73.850**	3.15	**117.859**	0.77
31.255	6.60	**75.292**	2.96	**119.279**	0.70
32.652	6.51	**76.701**	2.82	**120.681**	0.71
34.094	6.36	**78.086**	2.71	**122.101**	0.74
35.503	6.13	**79.534**	2.65	**123.543**	0.70
36.922	5.97	**80.954**	2.51	**124.946**	0.69
38.353	5.80	**82.374**	2.43	**126.377**	0.70
39.756	5.77	**83.771**	2.35	**127.797**	0.69
41.193	5.67	**85.196**	2.27	**129.216**	0.65
42.595	5.50	**86.633**	2.14	**130.625**	0.70
44.043	5.48	**88.047**	2.09	**132.033**	0.66
45.446	5[illegible]	**89.449**	2.03	**133.464**	0.69
46.860	5[illegible]	**90.892**	1.92	**134.884**	0.61
48.302	5.19	**92.300**	1.87	**136.298**	0.60
49.716	5.11	**93.714**	1.73	**137.740**	0.62

APPENDIX E

NERD FILTER FUNCTIONS WRITTEN IN THE C COMPUTER LANGUAGE

The following functions are written with Microsoft C version 5.1 for the MSDOS version 3.10 (and higher) operating systems.

```
/*Functions*/

int     NERD (double, double, double, double *),        /* Calculates filter coeffs   */
        FilterData (int, double *, float x, float *);   /* Filters x data -> velocity*/

double        In0 (double);                             /* Bessel function            */
```

```
/*-----------------------------------------------------------------------------

          NERD nearly equal ripple differentiating filter.

     Function computes the coefficients of a nearly equiripple linear phase derivative filter
with an even number of terms. The derivative is computed at the centers of the sampling
intervals.

     Input:
          Lambda = stopband loss in dB
          Beta   = relative location of ideal edge of passband.
          Delta  = relative width of transition band.

     Output:
          Np =  number of filter coefficient pairs, 2Np returned (k = -Np, ... , 0, 1, 2,
                ..., Np-1).
          Filter = array of filter 2Np coefficients.

          Total span of filter is 2Np - 1 intervals.

-----------------------------------------------------------------------------*/
```

```
int     NERD        (

double Lambda, double Beta, double Delta,      /* λ, β, δ for filter    */
double *Filter                                 /* Filter array output*/
                    )
{
double m, Np2,                    /* Constants used in 'for' loop       */
       I0_Eta,                    /* Bessel function */
       Kf, Eta, BetaPi, theta,    /* Constants used in calculation */
       scale,                     /* Used to obtain unity slope in passband */
       *pFilter, *nFilter;        /* Pointers to filter's +ve & -ve coeffs    */

int    k;                         /* Index in 'for' loop */

       puts    ("\nThe filter characteristics are required:");

       if      ( (Beta * Delta) <= 0. || Beta > 1. || Delta > .5)
               {
               puts ("\n\nEither β or δ exceeds its range, try again!\n");
               return (0);
               }
       else    if ( 2 * Beta < Delta)
                       {
               puts ("\n\nWoops, the filter has no pass band because δ > 2β !\n"
                       "you should change these values");
               return (0);
                       }

       puts("");

       if      (Lambda > 21.)
               {
               if      (Lambda > 50.)
                       Eta = 0.1102 * (Lambda - 8.7);
               else    Eta = 0.58417 * pow(Lambda - 21., 0.4) +
                               0.07886 * (Lambda - 21.);

               Kf = 0.13927 * (Lambda - 7.95);
               }
       else    {       Eta = 0.0;    Kf = 1.8445; }

       Np = (int) floor ( Kf / (2. * Delta) + 0.75 );    /* Returned to calling function */
```

```
	for	(scale = 0., I0_Eta = In0 (Eta), BetaPi = Beta * Pi,
		Np2 = (double) (Np * Np), pFilter = Filter + Np, m = 0.5;
		m < (double) Np; k++, m++)

			{	/* Calculate +ve coeffs */
			theta = m * BetaPi;
			*pFilter = (-BetaPi * cos (theta) + sin (theta) / m) *
				In0 (Eta * sqrt (1.- m*m / Np2) ) / (I0_Eta* Pi * m);
			scale += *pFilter++ * m;
			}

	scale *= -2.;		/* scale = 2 Σ m Filter(k) */

/*	Scaling factor 'scale' for unity slope at zero frequency, it is used to adjust Filter. -ve
	k coeffs (nFilter) are then obtained from +ve coeffs. (pFilter). Scale is -ve so that
	dx/dt is +ve for +ve slopes */

	for	(pFilter = Filter + Np, nFilter = Filter + Np - 1, k = 0; k < Np; k++)
		{
		*pFilter /= scale;
		*nFilter-- = -*pFilter++;	/* set -ve coeffs. */
		}

	printf ("\n\tAn NERD filter with %d filter coefficients\nhas been created.\n\n", Np);

	return (Np);
}
```

/*———————————————————————————————

FilterData filters x array and outputs velocity array U.

Starting at element U_{Np} in array U_i the nested 'for' loop calculates:

$$U_i = \sum_{k=-N_p}^{N_p-1} b_k x_{i-k}$$

where i = Np to n-Np-1.

Note b_{-Np} => Filter[0], b_0 => Filter[Np], b_{Np-1} => Filter[2Np-1].

———————————————————————————————*/

```
int     FilterData      (

int     n,              /*      Number of points in x array */
double *Filter,         /*      Input array of filter coefficients calculated by NERD() */
float *x,               /*      Input array of distance data to be differentiated */
float *U                /*      Output array of calculated velocity data */
                        )
{
int     i, k;           /*      Indices used in 'for' loop */
float   *px, *pX,       /*      Pointers to *x */
        *pU;            /*      Pointer to velocity data          */
double *pFilter;        /*      Pointer to filter coeffs          */

        if      (Np < 2)        /* If Np < 2 must calculate filter first.    */
                return (0);

        printf  ("\tCalculating velocity data using a %d coefficient filter.\n", Np);

/*      U is expected to contain zeroes on entry, so the outer 'for' loop skips the 1st Np
        points.  The inner loop calculates Ui by multiplying array x by the filter
        coefficients.  The outer loop sweeps along the Ui and xi arrays together.    */

        for     (pU = U + Np, pX = x + Np,
                        i = Np; i < n - Np + 1; i++, pU++, pX++)
                for     (px = pX + Np - 1, *pU = (float) 0., pFilter = Filter,
                                k = -Np; k < Np; k++)
                        *pU += (float) (*pFilter++ * *px--);

        puts ("\n\nUs data have been calculated.\n");
```

```
        return(i);      /* no. of points in velocity array */
}

/*----------------------------------------------------------------------------

        function In0 ()

        Routine evaluates the modified Bessel function of zeroth order at real values of
        the argument.

        Input: x
        Returns modified Bessel function.

----------------------------------------------------------------------------*/

double          In0 (double x)

#define In0LIMIT 2.e-16
{
double          Bessel0 = 1.,       /* Desired function  */
                term_k,             /* Iteration error   */
                count;              /* Iteration count   */

        if (!x)
                return (Bessel0);

        x /= 2.;

        for     (term_k = 1., count = 1.;
                        term_k > In0LIMIT * Bessel0 && count < 50.; count++)
{
                term_k *= x * x / (count * count);
                Bessel0 += term_k;
                }
        return (Bessel0);
}
```

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13. ABSTRACT (*Maximum 200 words*)

The NSWC ELSGT is to be used as the standard test for the UN and the NATO to determine the shock sensitivity of candidate extremely insensitive detonating substances. This report presents the first complete experimetnal calibration of the ELSGT and the techniques used to obtain the calibration data. In particular, an improved method of differentiating photographic streak camera (x, t) data is described.

Streak camera data must be numerically differentiated to obtain wave velocities as functions of time or distance. For time-varying or structured data, techniques such as spline or polynomial fitting are frequently employed. These techniques are usually adjusted by the researcher until the results are acceptable. Consequently, the results can be biased by the method. A new, unbiased, efficient, and accurate method based on the Kaiser and Reed algorithm is described. This method will be demonstrated by its application to the first experimental calibration of the ELSGT.

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